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NOISE IN RECEIVING SETS

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The noise in receiving sets in first treated in this article as an acoustic phenomenon. The chief sources of noise in radio sets are then dealt with: the first tuning circuits and the first amplifier valves. As suitable quantities for judging a radio set as to noise the concepts "noise voltage" and "specific noise voltage" are introduced. Measures are studied which may be taken to keep the noise level low, as well as the cases where the use of low-noise valves offers advantages. After several remarks on the permissible ratio of noise to signal voltage, the variation of the noise voltage is studied as a function of the signal strength, with special attention to the influence of automatic volume control on this variation.

Introduction

As a consequence of the thermal motion of electricity in conductors irregular voltage fluctuations occur between two points of an electric circuit. Fluctuations of the anode current about its mean value occur in amplifier valves, due to the corpuscular nature of electricity. It has already been shown in this periodical that these voltage and current fluctuations are entirely random and may be represented by a spectrum in which all frequencies are present in equal intensity. These alternating voltages and currents are very small and cannot be observed directly. When they are sufficiently amplified, however, for instance a million times, and passed through a loudspeaker they will give rise to irregular vibrations of the air; the impression which these vibrations make upon the air is called noise. More familiar examples of a similar sound are the rustling of leaves or the sound of gentle rain in a wood.

Noise as an acoustic phenomenon

As already mentioned all frequencies are represented in equal intensity in the above-mentioned electrical vibrations; this is, however, not the case with the air-vibrations. All frequencies are not amplified to the same extent, and the loudspeaker itself is not equally sensitive for all frequencies.

The sound impression which the irregular air vibrations make upon the air depends upon the distribution of the intensity of the components of the acoustic noise spectrum; the impression is for example clearly different according to whether the high frequencies are more or less strongly represented or the low, and it is plain that in such a case a distinction can be made between a high, sharp noise and a low, dull noise. If a filter is introduced between amplifier and loudspeaker which passes a certain narrow frequency band, the noise gives rather the impression of a definite tone which is clearer the narrower the band chosen.

The impression of loudness which the noise makes on the ear is also very dependent on the spectral distribution of the air vibrations. A high and a low noise, which represent the same vibration energy, will not make the same impression of loudness on the ear. Estimations of the loudness of the noise will moreover vary very much among individuals, since the curves for the sensitivity of the ear also vary very much among different individuals.

The reproduction of a signal, music or speech, is in principle always accompanied by the above-described noise, the intensity of which depends chiefly on the amplification necessary for the signal. When the noise is not very weak compared with the desired signal, it will form an audible, more or less disturbing background, it may even render the spoken word unintelligible and music disagreeable. It is obvious that every attempt should be made to keep this disturbance as slight as possible: in other words every attempt should be made to make the impression of loudness of the noise as slight as possible compared with that of the desired signal. We have just seen that the impression of loudness of the noise is influenced by its spectral distribution of intensity; therefore this distribution, *i.e.* the frequency characteristic of amplifier and loudspeaker together, will exert an influence on the audibility and disturbing effect of the noise. Since a detailed treatment of this subject would lead us too far afield, we shall limit ourselves to the most general considerations.

If we look for the most favourable frequency characteristic, it is obvious in the first place that the frequencies which never occur in the desired signal need not be amplified; the addition of new frequencies to the spectrum of the noise will, when the energy of the remainder remains unchanged, only be able to increase the noise impression, in that case without any advantage to the reproduction of the desired signal.

This principle can be further extended, and frequency ranges which are not of essential importance in the reproduction of music or speech may be omitted entirely. It is known that speech may be reproduced intelligibly with only the frequencies between 300 and 2 000 c/s, and music often retains its natural character when frequencies below 150 and above 3 000 c/s are cut off. If the high frequencies are cut off, the high sharp noise disappears, the energy of the speech or music is thereby often only slightly less, and one obtains the impression that the set has less background noise. Every owner of a receiving set can observe this when he reduces the amplification of the high frequencies with the help of the tone control in listening to a weak station.

This changing of the characteristic in order to make the impression of the ratio of signal to noise intensity more favourable is carried out at the expense of the quality of reproduction. The intensity relation between the different frequencies should of course preferably be exactly the same in the reproduction as it was in the original music or speech, so that the sensitivity of the whole transmitting and receiving installation, including amplifier and loud speaker, must be equally great for all frequencies, even for the frequencies (the highest and the lowest) which only occur to a smaller extent.

By weakening the high tones of a set which reproduces the high tones correctly (for instance by introducing a suitable filter passing only low tones, or, more simply, by placing a condenser across the terminals of the loudspeaker), the set will undoubtedly produce less noise, but this will be achieved at the expense of faithful reproduction. If one is particularly concerned with the noise, the set may be considered better in its changed conditions; there must therefore be a compromise between quality and absence of noise, or better, the quality (fidelity) of the set must be adapted to the circumstances: if the level of noise is so low that it is not heard, then the highest requirements of faithful reproduction may be demanded; if, however, the noise level is so high that it becomes annoying, it is desirable that the frequency spectrum of the reproduction be restricted to the most essential frequencies.

In order to decide which of two sets is more favourably constructed with respect to noise, it is obvious that it is not correct to compare directly the noise of a set which gives a good reproduction of the highest and the lowest frequencies with the noise of a set which only reproduces a limited range of frequencies. The noise of the first set will certainly become less when its frequency characteristic is made the same as that of the second, which can always be done by cutting off the highest and the lowest frequencies. Therefore, *in order to compare the noise of two sets we must make their reproduction characteristics the same:* then the differences in position and intensity of the sources of noise in sets of different types of construction are clearly shown. The influence of these differences, which are generally more important than the influence of the reproduction characteristic, will now be discussed.

Chief sources of noise

As in the previous articles in this periodical on this subject[1]), we shall not consider abnormal sources of noise, but confine ourselves to those sources whose presence is inherent in the amplifiers used, namely the thermal motion of electricity in electrical circuits and the shot effect of the anode current of amplifier valves. The influence of both effects can be represented by supposing that, in series with every resistance R, there is a fluctuating E M F, whose mean square $\overline{V^2}$ is proportional to the resistance, and that upon every anode current, a fluctuation is superimposed whose mean square is proportional to the mean anode current $\overline{I}$. For every frequency band $\Delta\nu$ the same contributions are obtained:

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[1]) M. Ziegler: The causes of noise in amplifiers, Philips techn. Rev. **2**, 136, 1937; Noise in amplifiers contributed by the valves, Philips techn. Rev. **2**, 329, 1937.

$$\Delta \overline{V^2} = 4\,kT\,R\,\Delta\nu, \cdot \cdot \cdot \cdot \cdot \quad (1)$$

$$\Delta\,\overline{(I_a - \overline{I}_a)^2} = F_a{}^2\,2\,e\,\overline{I}_a\,\Delta\nu \cdot \cdot \cdot \cdot \cdot \quad (2)$$

In an amplifier which consists of electrical circuits and amplifier valves there are therefore sources of noise at many points. All these fluctuations are entirely independent of each other, and the mean square of the total fluctuations is consequently equal to the sum of the squares of the contributions made by the individual sources of fluctuation. Not all of them will contribute the same amount to the noise issuing from the loudspeaker, since some noise voltages are amplified much more than others. In most cases, the effect of the thermal fluctuations in the elements of the circuit preceding the first amplifier valve and of the spontaneous anode current fluctuations of the first valve dominate over the others, because these fluctuations are amplified by the greatest number of valves. Suppose for example that the first valve amplifies ten times, then the contribution of a noise voltage between the grid and the cathode of the first valve to the total noise energy is 10^2 times as great as the contribution of an equally high voltage on the anode of this amplifier valve. The contribution of the latter voltage may then be neglected. In the case of a receiving set constructed according to the general details of *fig. 1* account need only be taken of the fluctuations of electricity in the first circuit and the shot effect in the first amplifier valve. The former give rise to a voltage on the tuned circuit which, for a narrow frequency range on either side of the resonant frequency, is given by:

$$\Delta \overline{V_k{}^2} = 4\,kT\,R_k\,\Delta\nu\,, \cdot \cdot \cdot \cdot \quad (3)$$

in which R_k represents the parallel resistance of the tuned circuit [2]).

The influence of the shot effect corresponds to that of an alternating voltage V_b on the grid of the first amplifier valve:

$$\Delta \overline{V_b{}^2} = F_a{}^2\,\frac{2\,eI_a}{S^2}\,\Delta\nu\,, \cdot \cdot \cdot \cdot \quad (4)$$

where S represents the slope of the valve [3]).

The square of the total voltage on the grid of the first valve with which we are here concerned is the sum of the two contributions above:

$$\Delta \overline{V^2} = \Delta \overline{V_k{}^2} + \Delta \overline{V_b{}^2} = \left(4\,kT\,R_k + F_a{}^2\,\frac{2\,eI_a}{S^2}\right)\Delta\nu\,. \quad (5)$$

Instead of the anode current I_a, the slope S and the noise factor $F_a{}^2$, one may use in equation (5) the noise resistance R_b, a quantity which has already been explained in this periodical [3]), as the value of the resistance between grid and cathode of an amplifier valve whose thermal fluctuating E M F contributes to the noise an amount equal to that contributed by the valve itself. Equation (5) then has the form:

$$\Delta \overline{V^2} = 4\,kT\,(R_k + R_b)\,\Delta\nu \cdot \cdot \cdot \quad (6)$$

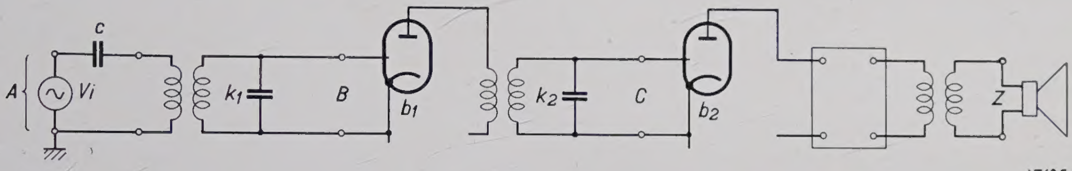

Fig. 1. Position of the sources of noise in a receiving set. The principal sources of noise are: first circuit k_1 and first amplifier valve b_1, second circuit k_2 and second amplifier valve b_2. The EMF induced in the receiver V_i acts in A. C represents the capacity of the aerial. The box represents the part of the apparatus not drawn. V_i causes the voltages $V_i\,\gamma^{AB}$, $V_i\,\gamma^{AC}$ and $V_i\,\gamma^{AZ}$ in B, C and Z respectively.

Ratio of signal to noise

In order to study the disturbing effect of the above discussed sources of noise at a certain strength of the desired signal, we should have to compare the sound impressions of disturbance and signal from the position of the observer. The practical conclusions with respect to the construction of the set will, however, as we shall see later, be fundamentally the same whether we take into account the frequency characteristic of the loudspeaker and the curve for the sensitivity of the ear, or whether confine ourselves to a comparison of the electrical energies of noise and signal which are conducted to the coil of the loudspeaker.

Let us imagine that the receiver is tuned to a carrier wave of the frequency ν which induces a voltage V_i in the aerial. This carrier wave is modulated sinusoidally: depth of modulation m, frequency of modulation s. This modulation may, as is known, be represented by the presence of two side bands with the frequencies $\nu + s$, and $\nu - s$, and the amplitude $^1/_2\, m V_i$. These side bands are amplified together with the carrier wave. If superheterodyning is employed, the frequencies of carrier wave and side bands become larger or smaller by the same amount. After detection and low-frequency amplification, as a result of the collaboration of the carrier wave and one of the side bands, a sinusoidal alternating voltage with the frequency s and the amplitude

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[2]) For a narrow range of frequencies on both sides of the resonant frequency the circuit behaves like a resistance R_k so that the formula (3) may be applied directly. Exactly the same result is attained by beginning with the fluctuating EMF of the coil resistance and calculating by means of Kirchhoff's laws the voltage thereby occurring across the terminals of the condenser.

[3]) Philips techn. Rev. **2**, 329, 1937.

$$^1/_2\, m\, V_i\, \gamma_s^{AZ}.$$

occurs at the output terminals. In the expression for the amplitude γ_s^{AZ} is a factor which we may call the amplification between the points A and Z of fig. 1. This amplification depends on the modulation frequency (signified by the subscript s) and will in general depend also on the strength of the carrier wave.

The low frequency oscillations from the two side bands are generally in phase, and we may assume that the amplification is the same for both. The total amplitude of the signal voltage is then exactly double the above amplitude, namely:

$$V_s = m\, V_i\, \gamma_s^{AZ} \cdot \cdot \cdot \cdot \cdot \cdot \quad (7)$$

The voltage fluctuations of the noise are amplified in exactly the same way as the side bands of the carrier wave received: they may also be considered as a type of modulation of the carrier wave. In contrast to the side bands, however, the low frequency voltage fluctuations, from the frequencies $\nu + f$ and $\nu - f$ in the fluctuations, are not in phase, but have an arbitrary phase relation. The mean square of the fluctuating voltage at the output side is therefore equal to the sum of the mean squares of the amplified voltage fluctuations for all frequency intervals on both sides of the carrier wave, and is given by:

$$\overline{V^2} = \Sigma\, 4\, kT\, (R_k + R_b)\, (\gamma_f^{BZ})^2\, \Delta f \cdot \cdot \quad (8)$$

γ^{BZ} represents the amplification between B and Z in fig. 1 [4]).

If we now assume, as in the case of the sinusoidal modulation, that the amplification is the same for the frequency $\nu - f$ as for the frequency $\nu + f$, we may replace the summation over all frequencies by twice the integral taken from 0 to ∞. The result may now be written in the form:

$$\overline{V^2} = 8\, kT\, (R_k + R_b)\, (\gamma_s^{BZ})^2 \int_0^\infty \left(\frac{\gamma_f^{BZ}}{\gamma_s^{BZ}}\right)^2 \mathrm{d}f \cdot \quad (9)$$

The integral in equation (9) has the dimensions of a frequency; it is connected with the "fidelity" of the receiver and is indicated by the letter G.

If we wish to take into account the frequency characteristic of the loudspeaker and the curve for the sensitivity of the ear, these two factors may be included in the amplification γ_f^{BZ}. The value of G may be slightly changed thereby, but there is no other change in the above calculation.

By dividing (9) by (7) we obtain finally the ratio of the electrical energy of noise to that of the signal:

$$\frac{\overline{V^2}}{V_s^2} = \frac{8\, kT\, (R_k + R_b)}{m^2\, V_i^2} \left(\frac{\gamma_s^{BZ}}{\gamma_s^{AZ}}\right)^2 \cdot G =$$

$$= \frac{8\, kT\, (R_k + R_b)}{(\gamma_s^{AB})^2\, m^2\, V_i^2}\, G, \cdot \cdot \cdot \quad (10)$$

in which γ^{AB} represents the amplification between the aerial and the source of fluctuation (the grid of the first amplifier valve). The ratio of noise to signal evidently does not depend upon the magnitude of the amplification γ^{BZ}. For the random fluctuations which cause the noise, therefore, just as for every other form of interference, it is true that their ratio to the desired signal remains the same no matter what the amplification applied to signal and interference.

Noise voltage

We have seen that at the output side of the apparatus the ratio of the signal to the noise due to the first valve and the first circuit does not depend upon the amplification γ^{BZ}. Besides the input signal V_i and its depth of modulation only the square of the following quantity occurs:

$$\sqrt{8\, kT\, (R_k + R_b)\, G}/(\gamma^{AB}).$$

The above quantity has a simple meaning: it is exactly equal to the R.M.S. value of the fluctuating voltage of the first valve and the first circuit divided by the amplification between the aerial and the grid of the first valve, and therefore indicates the magnitude of a fluctuating E M F which, acting at the same place as the signal to be amplified, would cause noise equal to the contribution of the first circuit and first valve. We call this value the **noise voltage** V_r of the set.

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[4]) γ^{BZ}, like γ^{AZ}, depends upon the value of the input signal. If the signal is very weak the detector still works in the quadratic part of its characteristic, and an increase in V_i then improves the detection, so that γ^{BZ} increases. If V_i increases still more the detection will finally cease to improve, and, due to the automatic volume control which usually commences to operate then, the amplification will decrease. If a very weak signal is fed to a receiving set, and then allowed to increase, an increase of the noise will at first be observed followed by a decrease.

Until now only the voltage fluctuations in the first valve and first circuit have been taken into account. In the following we shall also take into account the contribution of the second valve and the second circuit (at C in fig. 1), and we thus obtain for the noise voltage the following expression:

$$V_r^2 = 8\,kT\left[\frac{R_{k1}+R_{b1}}{(\gamma_s^{AB})^2}\,G_1 + \frac{R_{k2}+R_{b2}}{(\gamma_s^{AC})^2}\,G_2\right] \cdot \quad (11)$$

In general the amplification between B and C will be independent of the frequency in the range of frequencies which contribute to G.

Then $G_1 = G_2 = G$.

Further by taking into account that:

$$\gamma^{AC} = \gamma^{AB}\,\gamma^{BC},$$

equation (11) may be simplified to:

$$V_r^2 = 8\,kT\,G\,\frac{\left[R_{k1}+R_{b1}+\dfrac{R_{k2}+R_{b2}}{(\gamma_s^{BC})^2}\right]}{(\gamma_s^{AB})^2} \quad \cdot \cdot \quad (12)$$

The expression within brackets has the dimensions of a resistance and for the sake of simplicity it will be represented by $\mathfrak{R}$.

Experimental determination of the (specific) noise voltage of a receiving set

The practical importance of the noise voltage or specific noise voltage will be made clearer by means of a discussion of the way in which it is determined experimentally.

In the arrangement of *fig. 2* aerial and earth terminals of the set to be investigated are connected *via* an artificial aerial with a signal generator which produces a sinusoidal voltage of suitable amplitude and of a frequency to which the set is tuned.

Instead of the loud speaker coil there is a square law meter of equal impedance. Due to noise fluctuations the meter will show a deflection which, according to equation (9) with the simplifications introduced subsequently, corresponds to the square of a voltage of the value:

$$\overline{V^2} = 8\,kT\,G\,\mathfrak{R}\,(\gamma_s^{BZ})^2.$$

If the carrier wave is now modulated sinusoidally with a signal of frequency s, the deflection is increased by the added tone energy:

$$V_s^2 = (m\,V_i\,\gamma_s^{AZ})^2.$$

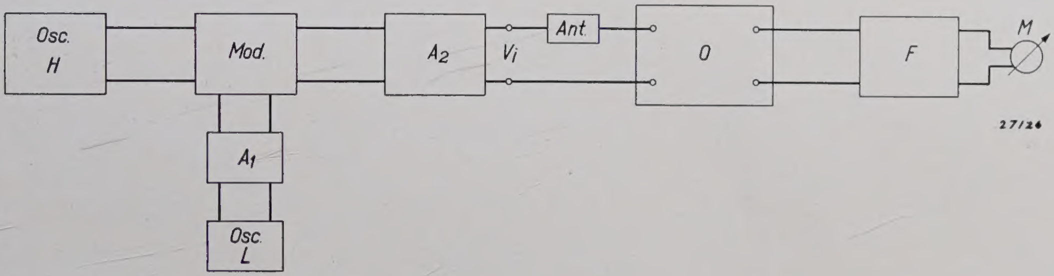

Fig. 2. Diagram of the layout for measuring the specific noise voltage of receiving sets. In the modulator the high-frequency voltage of the oscillator H is modulated by means of a 500 cycles alternating voltage from the oscillator L whose amplitude can be adjusted at any value with the attenuator A_1. The modulated voltage is reduced with A_2 to the desired value V_i and is conducted to the aerial terminals of the receiving set over the artificial aerial. The square law meter M is connected to the receiver *via* a bandpass filter F (passing frequencies from 300 - 1 300 c/s), and indicates the electrical energy of the modulation tone and of the noise within the band passed.

Specific noise voltage

At the beginning of this article it was explained that we shall concern ourselves chiefly with the difference in noise which may still occur in different sets after the frequency characteristics of the reproduction have been made the same. This means that the noise voltages refer to the same value of G. We shall always use for G the value 1 000 sec^{-1} and call the noise voltage corresponding to this value the specific noise voltage V_{rsp}.

From equation (12) it follows that:

$$\begin{aligned} V^2_{rsp} &= 8000\,kT\,\mathfrak{R}/(\gamma_s^{AB})^2 \\ &= 0.322{\cdot}10^{-4}\,\mathfrak{R}/(\gamma_s^{AB})^2\,(\mu\text{V})^2 \quad \cdot \cdot \quad (13) \end{aligned}$$

The depth of modulation can now be so adjusted that the deflection due to noise and tone energy together is just double the deflection due to noise alone. Then the tone energy is equal to the noise energy. The depth of modulation at which this occurs is called the noise modulation depth m_r. From this definition it follows that:

$$m_r\,V_i\,\gamma_s^{AZ} = \sqrt{8\,kTRG}\;\gamma_s^{BZ},$$

$$m_r\,V_i = \sqrt{8\,kTRG}/\gamma_s^{AB} = V_r.$$

We see from this that the noise voltage is equal to the product of the aerial signal and the noise modulation depth. Measurement of the noise voltage thus becomes the determination of the noise modulation depth at a known aerial signal.

In order to obtain the specific noise voltage, the noise voltage must be multiplied by 1 000/G. The determination of G which is necessary for this is rather elaborate. A simpler method consists in the use of a bandpass filter which passes only those frequencies between 300 and 1 300 c/s, and which is connected between the output terminals of the set and the quadratic meter. Since the fidelity curves of receiving sets are generally fairly flat in this frequency range, the value of G of the whole setup will be 1 000 c/s in sufficiently close approximation.

An additional advantage in the use of such an output filter is that the 50 cycles alternating voltage and several of its harmonics are eliminated. These fluctuations from the mains may otherwise easily lead to a disturbance of the noise measurements in alternating current receivers.

The influence of amplifier valves and oscillatory circuits on the noise of a set

The attempt to obtain as low a noise voltage as possible leads, according to equation (13) to two requirements:

1. The gain γ^{AB}, *i.e.* the voltage amplification between the aerial and the grid of the first valve should be as great as possible,
2. The total noise resistance:

$$\mathfrak{R} = R_{k1} + R_{b1} + \frac{R_{k2} + R_{b2}}{(\gamma_s^{BC})^2} + \dots$$

must be as small as possible.

A large value of γ^{AB} is obtained by having a closely coupled aerial circuit with a sharp resonance curve. This requirement of a large gain is also necessary for the sensitivity of the set, but we shall not discuss this point here.

The value of the noise resistance at a given amplification depends upon the noise resistances of the amplifier valves and the parallel resistances of the circuits used. If definite requirements are made of amplification, selectivity, etc. then the characteristics of the circuits, including R_{k_1}, R_{k_2}, etc. are thereby determined; with equal amplification, however, the contributions of the various amplifier valves to the noise voltage may be very different.

Previously in this periodical (Ziegler, *loc.cit*) it was derived that the noise resistance of an amplifier valve is given by:

$$R_b = 20\,000\ F_a{}^2 \frac{I_a}{S^2} \text{ ohm}, \quad \dots \quad (14)$$

where I_a is the anode direct current in mA and S the slope in mA/volt. The factor $F_a{}^2$ has a value which varies between 0.05 and 1.

In the following table may be found the values calculated for the noise resistance of the octode EK 2 (oscillator frequency-changing valve), of the high-frequency pentode EF 5 and of the "silentode" EF 8.

	I_a	S	$F_a{}^2$	R_b
	mA	mA/volt	—	Ω
EK 2	1.5	0.5	0.67	80 000
EF 5	8	1.7	0.27	15 500
EF 8	8	1.8	0.062	3 200

When the circuit resistances are high compared with the noise resistances of the valves, the replacement of these valves by valves of a type having lower noise resistance will give much less improvement than when $\mathfrak{R}$ is mainly determined by the valves.

For the sake of illustrating the various ratios occurring in practice, the specific noise voltage will be calculated for three sets, on the medium wave at 1 000 kc/s when the circuit resistance may be 100 000 ohms, and on the shortwave at 10 000 kc/s where 8 000 ohms is a normal value for R_k.

The first set has an octode EK 2 as first valve, the other two begin with a stage of high-frequency amplification preceding the frequency-changing valve. The valves used are the pentode EF 5 and the silentode EF 8, respectively.

Additional data of importance for our considerations will be found in the above table, where the calculated values of the noise energy in the different cases are given.

With the assumed value of γ^{BC} the second valve and the second circuit do not have an influence on the noise voltage more than a few per cent.

It may be seen from the table that on short waves where the circuit impedance is comparitively small, the application of a high-frequency amplifier stage preceding the frequency-changing valve, and particularly the use of a silentode (set C) gives an important decrease in the noise energy, which is essential for good reception on short waves. On the medium waves the contribution of the noise resistance of the amplifier valves to the total noise appears from the table to be comparitively small, so that in the case in question the improvement obtained by the use of high-frequency amplification is not great.

The contribution of the amplifier valves becomes much greater, however, if the valves are used at a lower anode current. This may easily be seen from formula (14): the noise factor F_a does not change much, but S^2 decreases much more rapidly than I_a, so that R_b increases. On decreasing the slope of the first valve by a factor of ten the noise resistance of the octode EK 2 used in set *A* is about 800 000 ohms and the noise resistance of the silentode used in set *C* amounts to 30 000 ohms. The noise voltage of the first stage of set *A* will then, at 1 000 kc/s be 2.24 times as much, while that of the first stage of set *C* only increases by 14 per cent. It may therefore be seen that the advantage of amplifier valves with low noise resistance can be realized even at high values of the circuit resistance.

Calculated values of the specific noise voltages of three sets at 1000 kc/s

No.	R_{k_1}	first valve	R_{b_1}	γ^{BC}	R_{k_2}	second valve	R_{b_2}	R	γ^{AB}	V_{rsp}	Noise *) energy
	Ω		Ω		Ω		Ω	Ω		µV	
A	100 000	EK 2	80 000	50	100 000	EF 5	15 000	180 046	5	0.48	1.72
B	100 000	EF 5	15 000	10	100 000	EK 2	80 000	116 800	5	0.39	1.14
C	100 000	EF 8	3 000	10	100 000	EK 2	80 000	103 800	5	0.366	1.00

Calculated values of the specific noise voltage at 10,000 kc/s

A	8 000	EK 2	80 000	50	8 000	EF 5	15 000	88 092	1.5	1.12	7.38
B	8 000	EF 5	15 000	10	8 000	EK 2	80 000	23 880	1.5	0.585	2.00
C	8 000	EF 8	3 000	10	8 000	EK 2	80 000	11 880	1.5	0.413	1.00

*) The noise energy of set C has been chosen as the unit of noise energy.

The variation of the noise resistance as a function of the aerial signal. Noise graphs.

If the adjustment of the amplifier valves to maximum steepness of slope, for which the above values of the noise voltage have been calculated, was retained for every value of the aerial signal, the noise voltage would be constant and independent of the value of the signal.

In modern receiving sets the adjustment of the amplifier tubes is, however, influenced by the strength of the signal; when it becomes greater the negative bias of the control grids increases automatically, and the amplification becomes less, so that the output changes only little, and overloading with the accompanying interferences and distortions is avoided.

The increase of the negative grid voltage has two results with regard to the noise voltage. In the first place the noise resistances of the amplifier tubes increase very much, as we have already noted, because the anode current does not decrease as rapidly as the square of the slope (see equation 14)). In the second place the amplification γ^{BC} decreases so that in equation (12) the contribution of $(R_{k_2} + R_{b_2})/(\gamma^{BC})^2$ to the noise resistance increases. Both of these changes result in the fact that the noise voltage increases when the automatic volume control begins to work upon increase in the input signal. On the other hand the signal strength also increases, so that the ratio of signal to noise will in general be more satisfactory. Since the noise voltage is not constant, the quality of a receiving set with respect to noise cannot be determined by a single measurement of the noise voltage. One should investigate how the noise voltage changes with the amplitude of the aerial signal. The results of measurements on several types of apparatus are given in the noise graphs of *fig. 3* where the noise voltage is plotted against the aerial signal on a logarithmic scale. The continuous lines refer to an apparatus with high-frequency amplification and a silentode, and are lower than the dotted curves which refer to an apparatus with an octode as first valve. At low signal strengths the curves are horizontal, since here the automatic volume control is not yet in operation or has no appreciable effect; at high signal strength the curves have an upward trend.

Permissible ratio between noise and signal

In order to draw practical conclusions from the noise voltage calculated and measured it is important to know what is the permissible ratio between noise and signal. According to formulae (10) and (12) this ratio, measured electrically, is equal to $V_r^2/m^2V_i^2$. The disturbing impression of the noise will therefore depend mainly upon the relation between the noise voltage V_r and the modulation voltage mV_i. Further the frequency characteristic and the reproduction will be important because they affect the character of the noise. The absolute value of the noise energy also plays a part of course in connection with the threshold sensitivity of the ear.

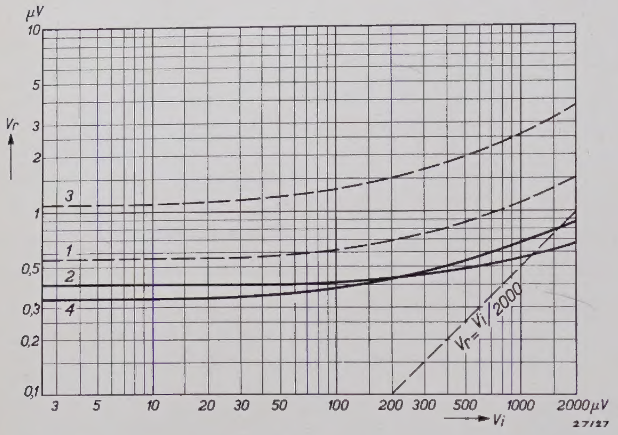

Fig. 3. Noise graphs. The specific noise voltage is plotted as a function of the aerial signal for two characteristic sets and at two frequencies.

Curve 1: first valve a frequency-changer; frequency 1 000 kc/s
Curve 2: first valve a silentode; frequency 1 000 kc/s
Curve 3: first valve a frequency-changer; frequency 10 000 kc/s
Curve 4: first valve a silentode; frequency 10 000 kc/s.

The straight line at 45° is the line $V_r = V_i/2\,000$. For the values of V_i to the right of the intersection of this straight line with the curves of the noise voltages, the noise is practically inaudible.

The question as to the permissible value of V_r/mV_i is not precise enough in its simple form: whether a value is permissible or not depends upon many circumstances and considerations; in the first place it depends upon the nature and strength of interferences other than background noise. A more precise formulation of the question is to ask the ratio between noise and signal at which, in the absence of other disturbances, the noise is so nearly inaudible that there is no necessity to diminish it further.

For a given apparatus (Philips 695A) the rather divergent data of a number of observers have given as an average result that with the level of reproduction normal for an average room the above requirement was fulfilled when:

$$\frac{V_{rsp}^2}{(mV_i)^2} = 2.8 \cdot 10^{-6} \quad \cdot \cdot \cdot \cdot \quad (15)$$

The specific fluctuation energy should therefore be 55.5 decibels lower than the energy of modulation. Since this result only establishes an order of magnitude it may also be used for rough estimations when one is concerned with sets having a different reproduction characteristic.

From (15) it follows that:

$$\frac{V_{rsp}}{mV_i} = \frac{m_{rsp}}{m} = \frac{1}{6}\,\%.$$

The specific noise modulation may not be more than $^1/_6$ per cent of the average signal modulation.

If we base our calculations on an average signal modulation of 30 per cent [5]) we find that for noise-free reception the specific noise voltage may not be more than 1/2 000 of the signal received.

If this rule is applied to the three sets studied in the previous section, and if one assumes that the noise voltage does not increase due to automatic volume control, it is found that on 1 000 kc/s and 10 000 kc/s the signal strengths in the table below are a necessary minimum for noise-free reception.

No.	Carrier wave 1000 kc/sec	Carrier wave 10.000 kc/sec
A	0.96 mV	2.24 mV
B	0.78 mV	1.17 mV
C	0.73 mV	0.83 mV

In the graph of fig. 3 the straight line $V_r = 1/2\,000\ V_i$ is drawn as a continuous line. The points of intersection of this straight line with the curves for the noise voltage indicate for these practical cases the minimum strengths of aerial signal necessary for noise-free reception.

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[5]) It should be noted here that the depth of modulation of good transmitters is often much less than 30 per cent, since this improves the quality of broadcasting, transmission and reception. For a modulation depth of 10 per cent, noise-free reception is only reached at $V_i = 6\,000\ V_r$.

EMISSION OF LIGHT IN THE POSITIVE COLUMN AT LOW PRESSURE

by W. UYTERHOEVEN.

537.525.8

As an introduction the phenomenon of self-absorption is briefly discussed with its influence on the occurrence of excitation and ionization by steps, as well as the Doppler effect in the emission of light. The light emission of the positive column in neon, sodium vapour and mercury vapour at low pressure is dealt with, and the conditions for maximum efficiency are considered. Finally several peculiarities of low pressure columns in alternating current discharges are studied

In the following we shall consider in detail the most striking property of the positive column, its *emission of light*. We shall confine ourselves to discharges in sodium vapour, neon and mercury vapour at low pressure which are used technically for illumination: the first in sodium lamps and the other two in red and blue illuminated advertising signs.

It has already been mentioned in a previous article ¹) that the excitation of atoms by electrons, which is the cause of light emission, is only a byproduct of the ionization necessary for obtaining the charged particles. It is obvious that we wish to produce this important "by-product" with the greatest possible efficiency. The conditions for this efficiency are dependent on the nature of the gas or vapour atoms which are used for the transformation of electrical into light energy. In the case of sodium a low pressure is used for the discharge, with mercury a high pressure is an advantage.

In studying the light emission of the positive column we repeatedly encounter the phenomenon of self-absorption, which we shall first discuss briefly.

Self-absorption of resonant radiation

By the term self-absorption we mean the property of a gas (or vapour) of being able to absorb the radiation which it naturally emits. Let us suppose that a sodium atom is brought from the zero state to the 2.1 V state by electron excitation (cf *fig. 8*). After an average of about 10^{-8} s the excited atom gives up the energy absorbed in the form of yellow sodium light and returns to the zero state. If this radiating atom were alone in the tube, or among atoms of a rare gas, the radiation would immediately leave the tube (*fig. 1a*). Actually, however, such a radiating atom is always surrounded by a large number of non-excited sodium atoms. These latter atoms easily absorb the radiation of wave lengths 5 890 and 5 896 Å and become excited atoms in the 2.1 V state ²). It then takes an average of 10^{-8} s again before the newly excited atom radiates its energy and absorption again occurs by still other non-excited atoms. This process of emission and reabsorption is repeated many times before the radiation leaves the tube in the case of lamps which emit resonant radiation (*fig. 1b*). For sodium lamps this number may be estimated at 10 000 under certain conditions. In this case therefore it is not 10^{-8} s before the radiation excited is passed on to the surroundings outside the tube, but $10^4 \times 10^{-8} = 10^{-4}$ s, so that there is an apparent lengthening of the life of the excited atoms. We shall see later from the spectra that for an economical production of sodium light self-absorption should be avoided as much as possible, while for the production of mercury light a high self-absorption is favourable. It is clear that the chance of excitation in steps is very much increased by the phenomenon of self-absorption. If both of these processes are to be promoted, self-absorption may on the one hand be increased by increasing the pressure, that is by increasing the number of absorbing atoms, and on the other hand the number of collisions between electrons and excited atoms may be increased by increasing the current density, *i.e.* by increasing the concentration of electrons. Both methods are used simultaneously in the high-pressure mercury discharge.

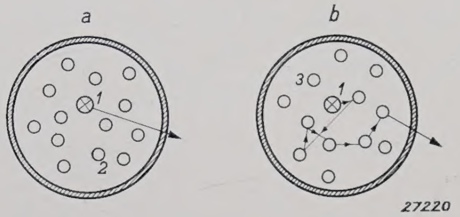

Fig. 1. Diagrammatic representation of self-absorption: *1* = excited sodium atom, *2* = rare gas atoms, *3* = normal, non-excited sodium atoms. In case *a*) the radiation leaves the tube directly, in case *b*) it is absorbed repeatedly before it leaves the tube.

Upon further study the phenomenon of self-

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¹) Philips techn. Rev. **3**, 161, 1938.

²) The 2.1 volt state consists of two states differing very slightly in energy content, called a doublet.

absorption is found to be very complex, due in part to the width of the spectral lines. With precise instruments it is found that a spectral line is never absolutely monochromatic, but always has a certain width, *i.e.* the light is not radiated in a single wave length, for example 5 889.963 Å, but in a region between 5 889.988 Å and 5 889.938 Å.

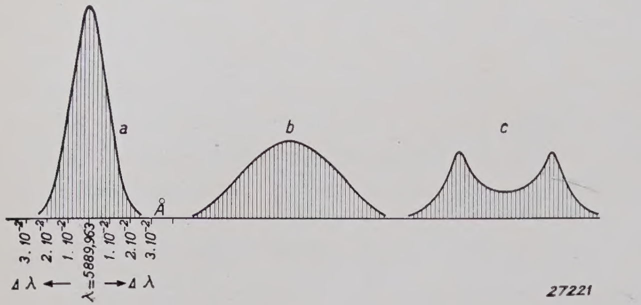

Fig. 2. *a*) Doppler broadening of the sodium line 5890 Å at 277° C (550° K). *b*) Form of the spectral line after the yellow beam has passed through an atmosphere of sodium vapour at lower temperature or in ionized condition.

One of the most important factors which causes this broadness of the lines is the Doppler effect which also appears in the propagation of sound. In the case of a source of sound, a tuning fork for instance, with a given frequency, the tone observed becomes higher when the source is moving toward the observer, and it becomes lower when it moves away from the observer. This phenomenon may be observed in the case of the whistle of a fast locomotive passing an observer: at the moment the locomotive passes the observer, the tone of the whistle suddenly becomes lower. In the positive column the spectral line which is observed is due to the simultaneous radiation of a large number of excited atoms. These atoms take part in the random thermal motion of the atoms, so that upon radiation a number of them are moving toward the observer and an equal number in the opposite direction. The thermal velocities of the atoms occurring in a low pressure column discharge are of the order of several hundred metres per sec. Although these velocities are small compared with the velocity of light ($c = 3 \times 10^8$ m/s), nevertheless they are sufficiently high to cause a measurable change in the frequency observed (comparable to height of a tone) and in the wave length. The resulting distribution of intensities as a function of the wave length due to this Doppler broadening may be seen in *fig. 2a* for sodium vapour at a temperature of 277° C (550° K).

The difficulties in the calculation of self-absorption arise because of the fact that the frequencies at the middle of the line are more easily absorbed than those at the edges. This changes the form of the line. If a beam of sodium light whose spectral line has the form *a*) of fig. 2 is sent through sodium vapour which, like the radiating vapour, has a temperature of 550° K, the spectral line after emergence will have become broader and have the form of *fig. 2b*. If on the other hand the beam passes through sodium vapour at a lower temperature, or through partially ionized sodium vapour in which cumulative effects may occur due to the presence of electrons, the line takes on the form of *fig. 2c*: the middle frequencies have been absorbed.

Finally we would point out that when there is sufficient self-absorption in a gas Lambert's law holds, according to which the brightness of a source of light is independent of the direction of observation. When strong self-absorption occurs the thickness of the layer through which the light passes when it leaves the tube directly is very small, so that the depth occupied by the discharge behind the wall has no influence. For a sodium lamp Lambert's law is approximately valid, this is, however, not so with a neon or a mercury lamp although self-absorption of the visible spectral lines also takes place in the two latter cases to a somewhat smaller extent since the absorbing atom is already in an excited state (*v. fig. 3*, and *fig. 13*). The number of excited atoms in the discharge is, however, always much smaller than the number of neutral non-excited atoms.

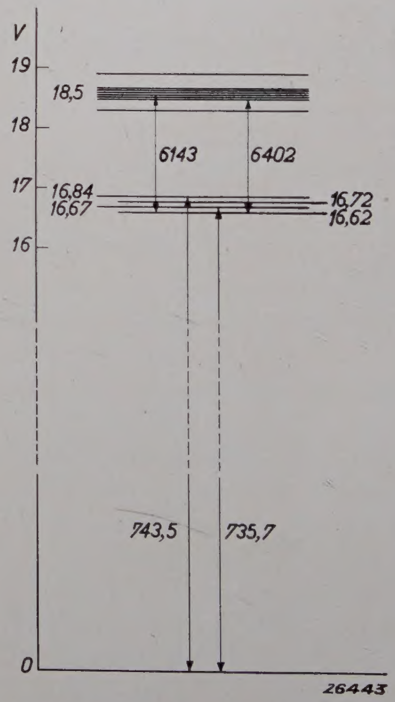

Fig. 3. Schematic representation of the stationary states of the neon atom which are important in the light emission of the positive column.

Neon column discharge

The complete spectrum of the neon atom is very complicated, but the portion of it which is important in the light emission of the positive column is given schematically in fig. 3 with the excited states. The four levels from 16.62 to 16.84 V we shall indicate collectively as the 16.6 V state; the higher levels in the neighbourhood of 18.5 V, which differ from each other by fractions of a volt only, we shall refer to collectively as the tenfold 18.6 V state. The visible lines are emitted here upon transitions from the 18.6 V group to the 16.6 V group. Several of the strongest lines are indicated, the accompanying number gives the wave length in Å. The resonance lines, which correspond to transitions from two of the 16.6 V levels to the zero state lie in the far ultraviolet at 744 and 736 Å because of the great difference in energy. The other two 16.6 V levels are both "metastable": The transition from these to the zero state is very improbable, so that it takes a much longer time before the energy is given off as radiation. Metastable states are usually destroyed by collisions either with the wall or with other atoms and electrons, while their life is of the order of 10^{-4} s.

Since two of the 16.6 V states are starting levels for the resonance lines, and the other two are metastable, it may be expected that the influence of cumulative effects will be strong in neon. On the other hand experience shows that the 16.6 V levels are very rarely excited by electrons. We therefore have the two following possibilities for light emission in the neon column:

a) The atom is excited from the zero state into one of the 18.6 V levels, passes over into one of the 16.6 V levels with emission of visible light and then returns to the zero state (*fig. 4a*).

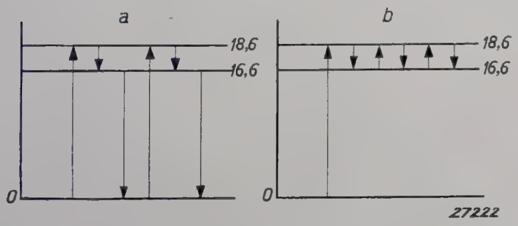

Fig. 4. Excitation of transitions in the neon spectrum which produce visible lines, *a*) from the zero state, *b*) from the 16.6 volt states.

Of the energy supplied, therefore, 18.6—16.6 = 2 V is radiated in the visible region. With the help of the curve for the sensitivity of the eye and the relative energy distribution in the neon spectrum one may calculate how much light is radiated when the energy of the visible neon lines taken together amounts to one watt; the result is found to be 137 lm. Therefore $\frac{2}{18.6} \times 100 = 10.8$ W are given off as visible light in the column per 100 W supplied. With the given energy distribution this gives $137 \times 10.8 = 1\,480$ lm, so that the "efficiency" of the column would be $1\,480/100 = 14.8$ lm/W [3]).

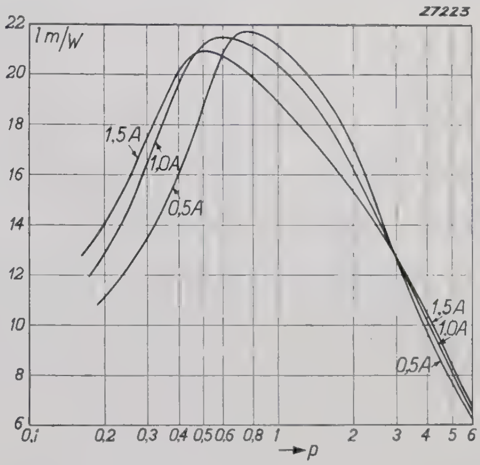

Fig. 5. Efficiency of the neon column with a diameter of 35 mm for various currents as a function of the pressure *p*.

b) The atom is again brought from the zero state to one of the 18.6 V levels and passes over into one of the 16.6 V levels with radiation of visible light. Before it returns to the zero state, however, it is again brought to an 18.6 V state by a collision with an electron for which 2 V are necessary and which are entirely transformed into visible light (*fig. 4b*). With a large number of successive excitations from the 16.6 V levels the efficiency becomes 137 lm/W.

In the actual discharge values are found which lie between the two extremes of case a) and case b), up to 30 lm/W. From this it follows that the process described under b) must play an important part, *i. e.*, the 16.6 V levels must act as a pseudo zero state. This phenomenon will be promoted by an increase of the self-absorption and especially by a lengthening of the life of the metastable atoms. As we have already mentioned these metastable atoms are destroyed by collisions with the wall or with other atoms. If the pressure is low they diffuse quickly to the wall, if the pressure is high many collisions with other atoms occur whereby they pass over into one of the two 16.6 V states which are not metastable. With a given diameter of tube and current, a maximum is found at a given pressure for the efficiency as a function of the pressure (*fig. 5*). Gases other than the rare gases have a very unfavourable influence on the life of the metastable states, so that traces of such gases considerably lower the efficiency.

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[3]) The energy used for ionisation has not been taken into account and cannot be neglected. The true efficiency should therefore be considerably less.

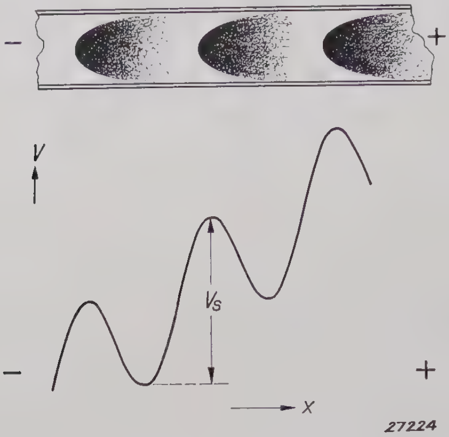

Fig. 6. Variation of the voltage and light intensity in a striated column (light-emitting parts are drawn darker).

The remarkable behaviour of neon upon excitation by electrons, when, instead of the lowest group of the 16.6 V levels being excited, the higher 18.6 V group is excited is encountered in the striae. Relative minima and maxima of the voltage (see *fig. 6*) which are superposed on the normal linear variation correspond to the successive dark and light spaces in the column. The increase in voltage V_s from minimum to maximum amounts to about 18.6 V. At the light spots the electrons give up their energy, and after having passed through about 18.6 V they may again become excited in the next light spot.

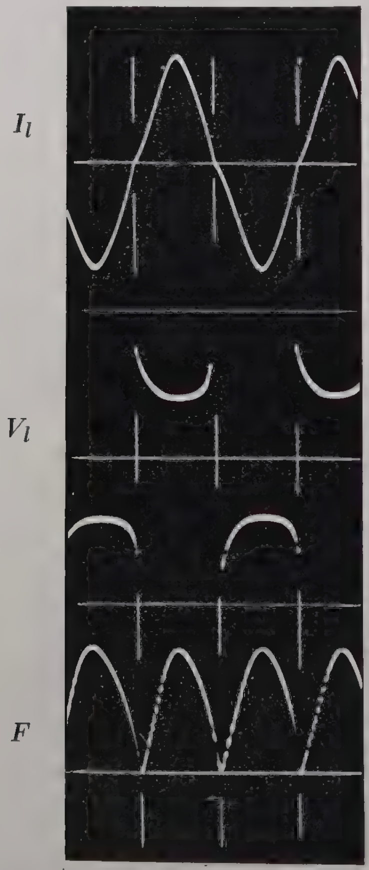

Fig. 7. Variation of lamp current I_l, lamp voltage V_l and light flux F for a neon lamp.

In the foregoing we have confined ourselves to direct current; since, however, practically all lamps work on alternating current we shall make a few brief remarks about the alternating current column in neon. *Fig. 7* gives the variation of current I_e, lamp voltage V_e and light flux F as functions of the time in the course of a full period. The oscillograms refer to a neon lamp for the irradiation of plants, which is supplied with 220 V through a choke (type 4311). The current is practically sinusoidal, the voltage however has a different form. When the current is zero, the lamp goes out and must then be re-ignited. For this purpose a higher voltage, the so-called re-ignition voltage, is necessary at the beginning of every cycle. Further the voltage is low in the middle of the cycle when the current is high, a consequence of the negative characteristic of the positive column. The light flux F varies approximatively as the current I_e.

Sodium column discharge

In the case of sodium lamps we are concerned with a typical source radiating resonance light. *Fig. 8* gives a scheme of several of the important energy levels; the transitions which lead to visible lines are represented by continuous lines and the wave lengths are given in Å. Spectral lines

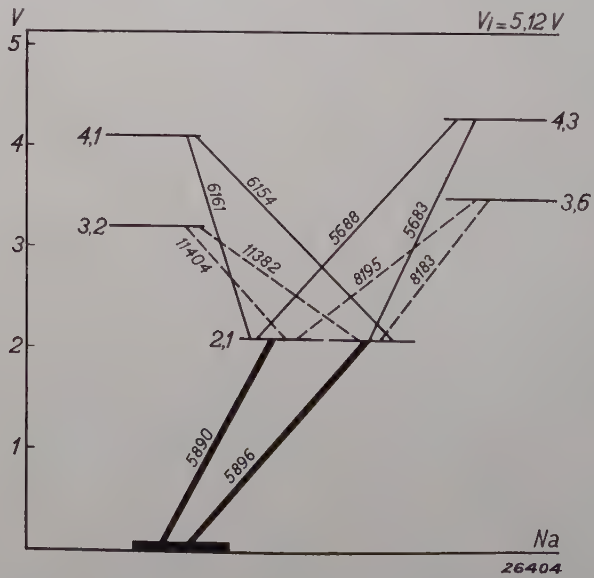

Fig. 8. Diagram of several of the energy levels of the sodium atom.

outside the visible region are indicated by dotted lines. It may be noted that, except for the double line 5 683—5 688, the resonance line 5 890—96 has the most favourable position of all lines with respect to the curve for the sensitivity of the eye. The relative sensitivity of the eye for $\lambda = 5\,890$—96 Å is about 0.765, so that when 1 W is radiated on this wave length, $0.765 \cdot 621 = 475$ lm is received [4]). The ideal would of course be to transform the electrical energy which is given to the electrons in the positive column entirely into yellow sodium radiation. This would mean a source of light with a yield of 475 lm/W. This is impossible for various reasons: there must always be some ionization to make possible the transport of current, and furthermore it is impossible to excite only the resonance line in a column. However, under favourable conditions about 90 per cent of the theoretically possible maximum for the sodium line can be attained, *i.e.* 425 lm/W.

These high values were obtained in the laboratory with a very low current density, the discharge tube being kept at the desired temperature of about 280° C in a special oven. This temperature is essential since otherwise the vapour pressure of the sodium would be insufficient. A lamp for practical use must, however, fulfil certain requirements, which need not be fulfilled by a lamp for laboratory tests. For example the lamp should be made as small as possible for a given light flux, both for the sake of decreasing the danger of breakage and so that the fixtures in which the lamp is to be mounted do not become too large. For this purpose the current density will be increased, and, because of the cumulative effects this is done at the expense of efficiency. With increasing current density the light flux only increases proportionally up to a certain limit, at higher currents the increase of light flux is less. *Fig. 9* shows this graphically.

Furthermore it is desirable that the lamp shall be selfheating and that it shall maintain its temperature without a special heating arrangement. As we have already stated the temperature of the coldest spot in the lamp must be about 280° C in order to obtain the necessary pressure of sodium vapour. At this temperature the heat dissipation to the surroundings is very important so that quite a large amount of energy is necessary per square centimeter of wall surface. This can be very much decreased by surrounding the lamp with an evacuated space since then heat dissipation by conduction and convection is practically eliminated and only heat radiation remains.

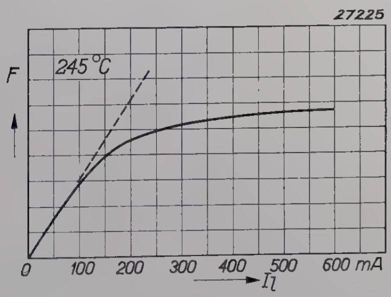

Fig. 9. Light flux F of the yellow sodium lines as a function of the current I_l at constant tube diameter and temperature.

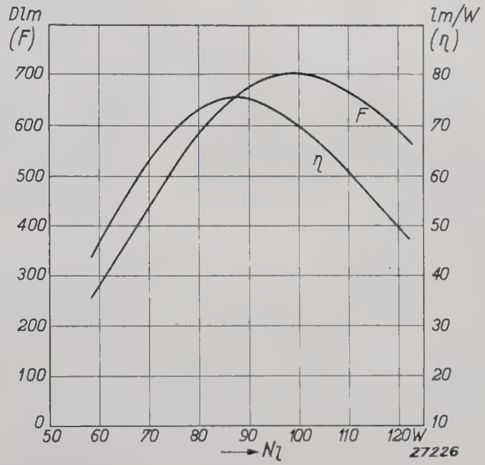

Fig. 10. Light flux F (in decalumens) and efficiency η (in lm/W) for a sodium lamp SO 650 as a function of the power on the lamp N_l.

Without special means a lamp containing only sodium would not ignite at ordinary temperature on the usual mains voltage, since the vapour pressure is only 10^{-11} mm. By the addition of a rare gas, usually neon, this difficulty is avoided. Upon ignition the discharge takes place in neon, the tube becomes warm and the sodium begins to vaporize. After several minutes so much metal is evaporated that the neon light is practically superseded by sodium light. With a good sodium lamp the neon light still contributes several per cent to the light flux, since the discharge takes place partly in neon and partly in sodium. By increasing the working temperature the vapour pressure of the metal can be made so high that the column discharge takes place wholly in the metal vapour, but the efficiency is then appreciably lower. *Fig. 10* illustrates this by means of the characteristic of a sodium lamp (SO 650) in which the light flux F is plotted as a function of N_l, the power in the lamp. At small values of N_l the light flux is also small, since due to the low temperature and pressure of sodium only neon light is radiated; at larger values of N_l the temperature and with it the vapour pressure of the sodium becomes greater so that more sodium light is also radiated. If, however, the value of N_l becomes greater than 100 W the light flux decreases because the efficiency decreases sharply due to the harmful cumulative effects. The range of values of N_l in which the light flux is a maximum is just the range where the neon as well as the sodium takes part in the discharge.

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[4]) It is known that 1 W radiated on the wave length $\lambda = 5\,550$ Å, which is the wave length of the maximum sensitivity of the eye, produces 621 lm.

Let us assume that in a neon column there is sodium on the walls at such a temperature that it vaporizes in the discharge. As soon as the metal atoms enter the discharge, they are excited and ionized. The excited atoms will give off the energy as yellow radiation and diffuse further toward the axis, the ions, however, under the influence of the electrical transverse field return to the wall and are neutralized there by recombination. If now the current density is sufficiently high all the evaporating sodium will be ionized in the neighbourhood of the wall, and will be unable to reach the axis of the tube. At the centre of the discharge therefore the neon will be excited and ionized, and it is to this that the red-radiating core is due. There are therefore a considerable number of neon ions formed, with $V_i \mp 21.5$ V, and one is inclined to assume that it would be advantageous to replace them by sodium ions, with $V_i = 5.1$ V, whereby with constant current the potential gradient and the consumption of energy ought to decrease and the efficiency ought consequently to increase. The fact that this is not so according to fig. 10, may be explained by keeping in mind that the harmful cumulative effects become stronger in such a case. In good sodium lamps the presence of sodium is limited by a suitable combination of current density, wall temperature and tube diameter to a thin layer near the wall. The light emission therefore takes place in this thin layer (*v.* fig. 12), and since there is no sodium at the core, self-absorption and loss of light by cumulative effects are restricted.

This behaviour of the column is very obvious in sodium lamps working on alternating current. *Fig. 11* gives the variation of lamp current I_l, lamp voltage V_l and light flux F as functions of the time. The current I_l again has a practically sinusoidal form due to the self-induction put in series for the purpose of stabilization. The voltage here, however, is very much deformed since the concentration of the available sodium is changed very much in the course of the cycle by ionization. At the beginning of the cycle the re-ignition peak may again be distinguished but is lower there than in the case of a cold lamp where the discharge takes place in neon. The voltage now varies at first in a way analogous to that of the neon discharge of fig. 7, except that the values occurring are lower since in the beginning the discharge takes place only in sodium. The current and the degree of ionization also increase with the time, in the axis of the tube all the sodium is ionized and at the wall temperature prevailing the rate of vaporization and of diffusion of the metal atoms are insufficient to supply the deficiency of sodium atoms, so that the neon now begins to take part in the discharge. This may be seen not only from the light emission, but also from the variation of the voltage which rises suddenly since neon with its high ionization potential ($V_i = 21.5$ V) is now being ionized. In this case the light flux does not vary directly as the current I_l in the phase (fig. 11) as in the neon discharge (fig. 7) but varies more irregularly due to the changing concentration of sodium.

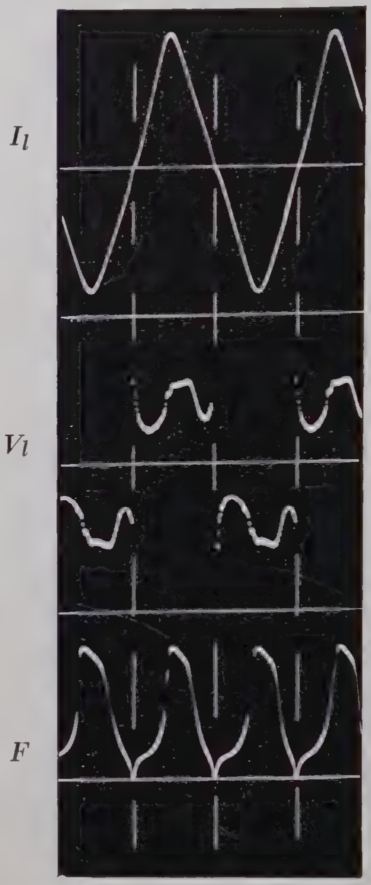

Fig. 11. Variation of lamp current I_l, lamp voltage V_l and light flux F as functions of the time for a sodium column lamp SO 650.

Finally *fig. 12* gives a series of photographs for comparison of the transverse cross section of a neon column and a sodium column taken at corresponding moments with an alternating current discharge. The upper series which refers to neon show clearly that the production of light, like the current density, has a maximum at the axis. In the middle of the cycle when the current I_l has reached its maximum the light intensity is also a maximum, and the light is excited mainly at the axis. The lower series refers to the column of a sodium lamp in ordinary use. At the beginning of the cycle, at a low current, the sodium light fills the whole cross section and it is at a maximum value on the axis. Half way through the cycle, at a high current, the sodium light is concentrated in a thin layer near the wall; neon light, however, now appears at the axis although of a much lower intensity. This is the so-called red core. At the end of the cycle, when the current has again become small, the sodium light again fills the whole cross section.

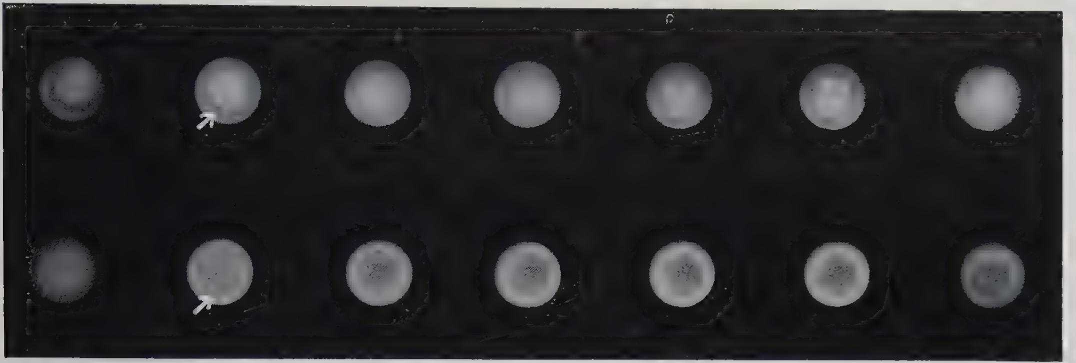

Fig. 12. Light in the cross section of a neon column (upper) and of a sodium column (lower) at different instants during the cycle of an alternating current discharge. The light border whose inner limit is indicated by the head of the arrow may be attributed to reflection on the inner surface of the tube. With neon the core is bright, with sodium it is dark.

Column discharge in mercury vapour at low pressure

Just as with sodium we are here concerned with a discharge in a metal vapour, mercury, in which however the added rare gas no longer takes part in the discharge during normal functioning of the lamp, since at the ordinary working temperature, about 80° C, the vapour pressure of the mercury is already quite high, namely ≈ 0.1 mm.

The main levels of the mercury spectrum are indicated in *fig. 13*, the continuous lines represent the transitions which correspond to spectral lines in the visible, the accompanying numbers indicate the wave lengths in Å. Transitions which give ultraviolet lines are here again indicated by dotted lines. As may be seen from the figure the two resonance lines lie in the ultraviolet (2 537 and 1 850 Å). All the lines in the visible are so-called higher lines, they occur upon transitions between two excited levels. In such a case the promotion of cumulative excitation by increase of pressure and current density is favourable for the efficiency. In the case of mercury, just as with neon, the stimulation of cumulative excitation is facilitated by the fact that 6.7 and 4.8 V are resonance levels and that 5.45 and 4.7 V are metastable levels with a longer life. With a given diameter of tube and constant current the efficiency of the column discharge as a function of the mercury pressure shows a maximum at a definite pressure (*fig. 14*). Upon increasing the pressure the efficiency at first decreases but later increases again when contraction occurs upon transition from the low pressure to

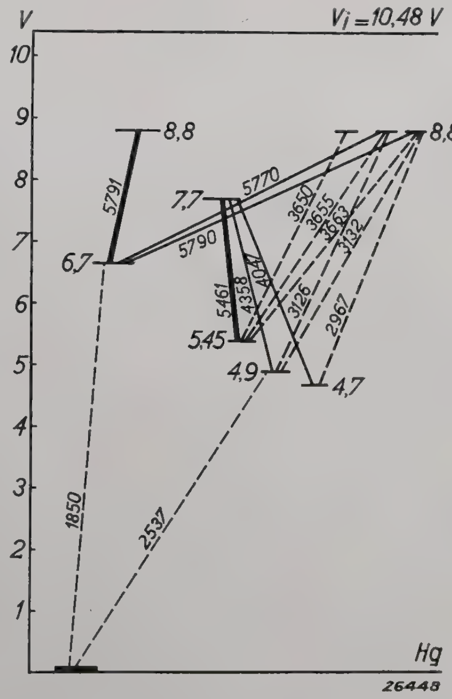

Fig. 13. Energy diagram of the mercury atom. Spectral lines in the visible region are continuous, those in the ultraviolet are broken. The numbers indicate the wave lengths in Å.

the high pressure discharge. The visible lines of the mercury vapour discharge at low pressure: 5 790 - 5 791 - 5 770 yellow, 5 461 green, 4 358 blue and 4 047 violet, are the same as appear in the high pressure discharge, the relative intensity is, however, different, so that the low pressure discharge appears bluer.

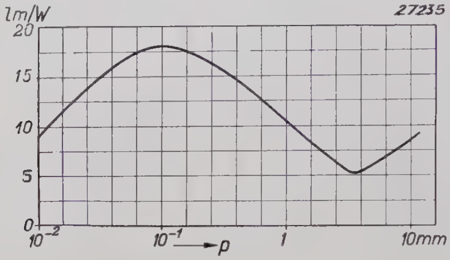

Fig. 14. Efficiency of a column discharge in mercury at low pressure, with a constant tube diameter (17 mm) and constant current, as a function of the pressure p.

The variation of lamp current I_l, lamp voltage V_l and light flux F as functions of the time with a low pressure mercury column is analogous to that of the curves given in fig. 7 for neon. As in the case of sodium the rare gas filling, usually a mixture of neon and argon, facilitates ignition in the cold state. It also plays an important part in the so-called re-ignition as is the case with all low pressure metal vapour lamps working on alternating current. Re-ignition occurs more readily since a greater number of charges are left over from the preceding cycle. Due to the presence of the rare gas the disappearance of the residual charges on the wall is retarded and the re-ignition voltage is thereby lowered.

COMPRESSION AND EXPANSION IN TRANSMISSION SOUND

by V. COHEN HENRIQUEZ. 534.322 : 534.86

The contrasts in speech and music which are reproduced electrically are limited by the ratio of intensity between the strongest sound which can be reproduced without distortion and the inevitable unwanted interference sound (noise and disturbances). This ratio is in general much smaller than the intensity ratios which appeared in the original sound. A faithful reproduction is therefore only possible by "compressing" the sound in one of the first links of the transmitting system and "expanding" it at the end in the reproduction apparatus. Several problems which occur in this process are discussed in this article, and a number of circuits are indicated which are suitable for this purpose

The sense of hearing enables us to observe air vibrations of very different intensities. On the one hand air vibrations with an amplitude down to 2×10^{-9} cm and a pressure of 3×10^{-4} dyne/cm^2 can just be heard, while on the other hand intensities which are 10^{13} times greater may be perceived by the ear without difficulties.

In the technique of electrical acoustics where the problem is to reproduce certain acoustic oscillations by electrical and mechanical means at a different spot or at a different time, the transmission of such a wide range of intensities is accompanied by difficulties. When we attempt to reproduce the acoustic oscillations through the different links of an electrical or mechanical system (*fig. 1*), it is fundamentally impossible to avoid the addition to the oscillations of a greater or lesser amount of irregular fluctuations which are commonly called noise, interference or hum, according to the nature of the sound which they produce. These fluctuations have been dealt with repeatedly in this periodical [1]).

For satisfactory reproduction it is necessary that the weakest acoustic oscillations emerge sufficiently above the level of disturbance, while the strongest oscillations must not lead to overloading. This condition is harder to satisfy the greater the ratio of intensities.

Attempts have of course long been made to limit the differences in intensity in the reproduction. For satisfactory reproduction it has been found unnecessary to be able to command the above-mentioned intensity range of 130 db between the barely audible sound and the limit imposed by feeling pain. In everyday life also we are always surrounded by a certain level of disturbance due to noises in which we are not directly interested such as the click of typewriters, the noise of engines, of the wind, etc. The intensity range commanded by an orchestra will not usually be more than 60 to 80 db. An intensity range of 60 db will in general be sufficient for the transmission of music.

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[1]) See articles by M. Ziegler on noise, Philips techn. Rev. **2**, 136 and 329, 1937; **3**, 193, 1938.

But even this intensity range is greater than that permitted by ordinary systems for electrical transmission of sound. The maximum intensity range usual in practice is 35 to 45 db for broadcasting transmitters, and 25 to 35 db for gramophone records.

This limitation is usually taken into account by artificially reducing the contrasts in the signal to be transmitted, for instance by regulating the amplification between the microphone and the transmitter (or the apparatus for cutting gramophone records) in such a way that the amplification is weak at loud passages and strong at weak passages. This regulation, which is called compression, may be done in various ways which we shall mention later ²). At the receiving end, after the signal has passed the different links where disturbances may be added to it, the original intensity relation may be restored by applying a method which is the inverse of compression; *i.e.* a higher amplification of the strong and a lower amplification of the weak signals.

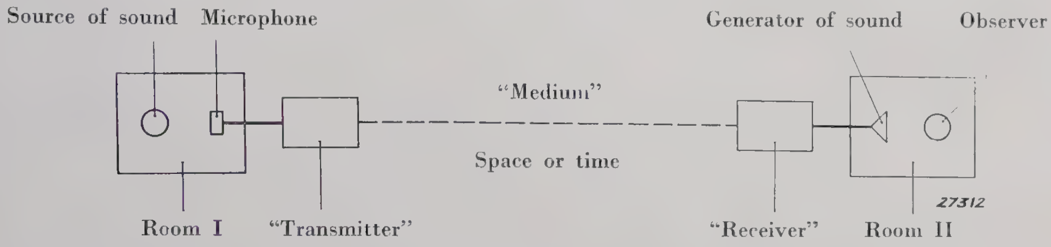

Fig. 1. The various links in sound transmission. "Transmitter" in its most general sense may for example also be an apparatus for the making of gramophone records or sound film. The concepts "Medium" and "Receiver" should also be taken in the same general sense. Each of these links may be the source of disturbances, for example:

Room I : Insufficient acoustic insulation with the result that street noises and the like penetrate.
Microphone : Noise of the microphone itself, insufficient shielding of connections sensitive to disturbances or interference.
"Transmitter" / "Receiver" : Noise from resistances and amplifier valves.
"Medium" : Atmospheric disturbances in radio transmission. Scratching of the needle on gramophone records.

In order to obtain precisely the correct intensity relations it is of course necessary that the second process, called sound expansion, is the exact inverse of the previous compression.

Compression and expansion characteristics

If it were always possible to match compression and expansion to each other, it would obviously be desirable to use them both to the greatest possible degree. Actually, however, the majority of receivers are not equipped with any device for expansion, and it is therefore necessary to choose the compression characteristic so that the reproduction remains as natural as possible even without expansion.

Let us imagine that a curtain were hung between an orchestra and the auditorium, and that the curtain had the property of reducing the strength of loud passages and increasing that of weak ones. The effect intended by the composer for the contrast between piano and forte would then be lost. It might perhaps be heard from the sound quality of the instruments that the musicians were playing loudly, but it would not be observed directly. Furthermore the subjective harmonics and combination tones which occur in the ear itself at great intensities would be missing. Compressed music would be less satisfying than normal music because the distribution of intensities intended by the conductor is destroyed.

Just as we may speak of distortion in the transmission of music when all the frequencies are not reproduced in the correct relation, compressed music must also be qualified as distorted. An attempt must therefore be made to compress the music as little as possible.

If we assume that the signal to be transmitted varies between 20 and 80 phons, while the signal passed by the apparatus may only be within an intensity range of 45 db, the compression charac-

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²) A form of compression upon sudden large variations in intensity is carried out by the ear, this is the so-called protective reflex of Kreide and Kato. If the ear is adjusted to the perception of weak noises and is then suddenly strongly stimulated, the *musculus tensor tympani* contracts as a reflex. The ear drum is thus drawn into such a position that the transmission of sound to the inner ear is very much hindered. A more familiar example of compression applied by an organ of the human body is the variation in the diameter of the pupil of the eye, which serves to lessen the variations in intensity of illumination of the retina.

teristic must be chosen so that the strength of the signal sent out increases only by 45 db between 20 and 80 phons. The characteristic may have various forms. Curves *a* and *b* of *fig. 2* are alike in that the intensity of reproduction is distorted only in a portion of the intensity range. Curve *a* more nearly resembles a "limiter", in which the amplification is decreased above a certain strength of signal, and forms a contrast to curve *b* in which the amplification is increased as soon as the signal falls below a certain limit. Such characteristics may be satisfactory when the fluctuations in intensity of the sound to be reproduced are so small that in general the right-hand portion of the characteristic is used, and compression only comes into action in exceptional cases. When, however, the intensity continually varies over the whole region of 60 db, it is better to distribute the compression uniformly as is done for instance in curve *c* of fig. 2. The corresponding expansion characteristic may always be found by exchanging ordinate for abscissa, in other words by drawing the mirror image of the curve with respect to a line at 45°. This is shown in *fig. 3*.

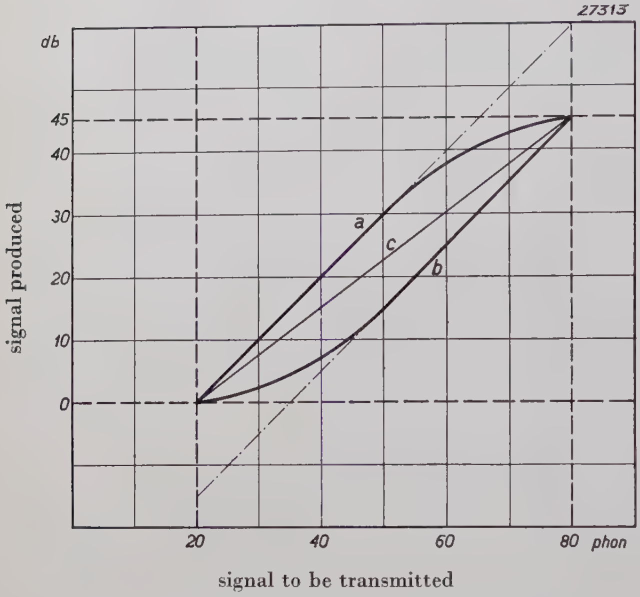

Fig. 2. Different compression characteristics which reduce variations in intensities from 60 db to 45 db.

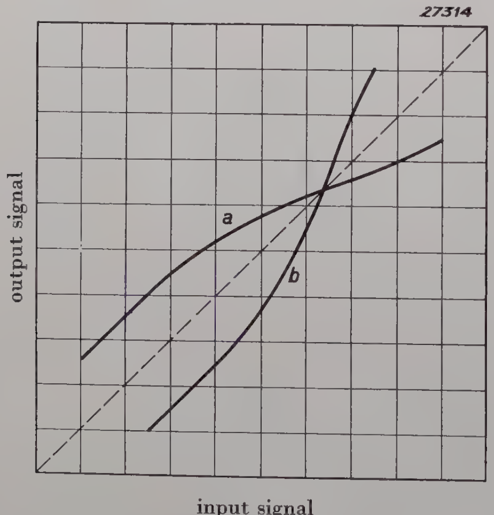

Fig. 3. A compression characteristic (*a*) and the corresponding expansion characteristic (*b*) may be derived from each other by drawing the respective mirror images in relation to a line at 45°.

The most satisfactory characteristic depends, as we have seen, upon the character of the music. If the same characteristic must be used for every case a uniform distribution of compression is to be preferred.

Compression is very often not carried out automatically but manually: the amplification is regulated by hand according to the intensity of the music. In this case there need be no permanent relation between the intensity of the original and of the compressed sound; it is then possible to take into account the special characteristics of the score [3]), and in this way to make the compression less noticeable. Against this is the objection that it is impossible to cancel this kind of compression accurately by automatic expansion in the receiver.

Time factor

In the foregoing we have seen that the application of compression or expansion means that the output intensity of a link in the transmission system (an amplifier for instance) does not increase proportionally to the input intensity. Before showing how this effect is achieved, we shall first point out the distinction between two fundamentally different possibilities:

1) The output amplitude at any given instant does not increase proportionally with the input amplitude at the same instant; the amplification is thus essentially non-linear.
2) The relation between output voltage and input voltage is linear; the amplification factor, however, is a slowly varying quantity which depends upon the average intensity over a certain interval of time.

The first system is practically unusable because the non-linear amplification of the signal leads to overtones, and a greater frequency range must therefore be transmitted. Moreover, with an inaccurately matched expansion characteristic overtones and combination tones will occur in the reproduction which are much more disturbing than an inaccurate reproduction of intensities.

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[3]) Regulation with reference to a score was discussed in an article by R. Vermeulen: The relationship between Fortissimo and Pianissimo, Philips techn. Rev. 2, 266, 1937.

In the second system non-linear distortions need not occur when the change in the amplification factor is made to take place so slowly by means of a retarding element that during a period the amplification of the lowest frequencies which are reproduced remains practically unchanged. On the other hand the regulation may not take place too slowly for the following reasons:

1) Upon a very sudden increase of intensity the retardation of compression may result in a temporary overloading of the apparatus, and therefore in temporarily distorted reproduction. The quicker the regulation, the less noticeable is this distortion.
2) If compression and expansion are not the inverse of each other, the regulation will itself become audible when regulation is too slow. For example after the beginning of a loud passage an increase in the amplification will be noticed due to increasing expansion. This will also be the case when compression is by hand and expansion automatic.

In order to make a suitable choice for the rate of regulation, we must consider several characteristics of the ear which are important in this connection. There exists for the ear a subjective time interval for the building up and dying out of sound. That is to say, there is no difference in observation between the sudden and the gradual beginning of a tone if the latter is not too slow. Let the intensity be represented as a function of time by:

$$I = I_{\text{final}} \left(1 - e^{-\frac{t}{a}}\right),$$

it will then be found that one observes no difference between $a = 0$ (sudden beginning) and $a = 0.07$ s. This interval of 0.07 s which is the subjective initial sound lag, is independent of the intensity of the sound.

If one listens to the difference between a tone which ends abruptly and one which decreases more gradually according to the equation

$$I = I_0\, e^{-\frac{t}{a}},$$

here again no difference is observed between $a = 0$ and values of a up to 0.1 s for weak, and up to 0.3 s for strong initial intensities. This shows that the sound impression continues to exist for a short time after the tone has been interrupted, and that the time necessary for its disappearance amounts to several tenths of a second.

The foregoing leads to the following choice of regulation times:

The initial time delay (increasing compression or expansion) should be less than 0.07 s; the final time delay should be within several tenths of a second.

These times are fortunately so long that signals with low frequencies (40 to 50 c/s) are reproduced without unpleasant distortion.

Meanwhile it was found desirable in practice to choose the final time delay somewhat longer since otherwise, with manual compression and automatic expansion, a disturbing effect appeared in the reproduction of percussion instruments. The sound of such instruments, that of the piano for instance, dies out in a damped oscillation. If the final time delay of the "expander" is chosen small, the amplification decreases during the dying out of the vibration of the note struck so that the note reproduced seems to die out more rapidly. With high expansion this effect may be very disturbing. With a final time delay of 0.5 to 1 s and not too high expansion the phenomenon is unnoticeable.

Adaptation of compression and expansion

If we wish to remove completely the distortion caused by the compression of the sound, not only must we choose the characteristic of the expander correctly, but we must in addition make the process of regulation in the expander such that the effect of regulation in the compressor is completely cancelled. This is actually possible, and consists of making the time lags of compressor and expander the same. If alternating voltage is supplied to the input

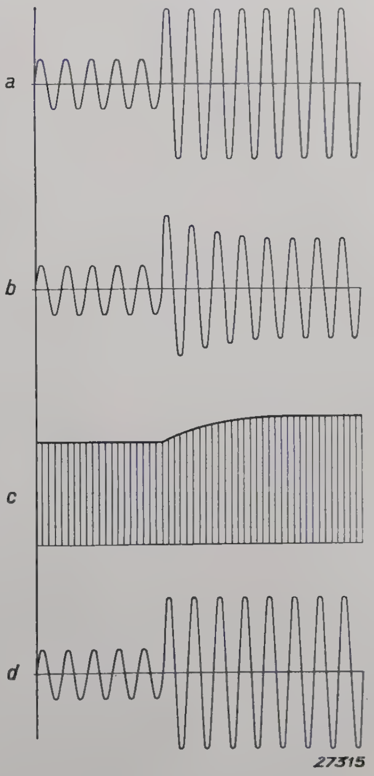

Fig. 4. Effect of delayed compression and expansion
a) Variation of the sound pressure;
b) Variation of the output signal of the transmitters;
c) Variation of the amplification factor of the receiver;
d) Variation of the output signal of the receiver.

side of a compressor and this voltage suddenly changes in amplitude (*fig. 4a*) the output voltage may be represented as a function of time by fig. 4*b*. If such a signal is now supplied to an expander the amplification factor of the receiver will increase gradually after the sudden change in signal strength and vary according to fig. 4*c*. The signal produced by the receiver is equal to the product of the input signal (curve *b*) and the amplification (curve *c*), and with suitable construction of the retarding element it may be made to correspond exactly with curve *a*.

Circuits

The usual circuits for automatic compression or expansion may be divided into two main groups:

A) Circuits in which the amplification is influenced by the alternation of the voltage relations of one or more amplifier valves,

B) Circuits in which use is made of the change in resistance of a filament upon being heated by an electric current.

We do not intend to give a complete survey of the possible circuits; we shall only discuss several possibilities in a general way.

A. Influence exerted on the amplification by a change in the voltage relation of amplifier valves

For changing the amplification a voltage is necessary which is dependent on the intensity of the signal. This may be obtained by rectifying the signal; the result of this detection, the regulation voltage, is then fed to the regulating amplifier over suitable retarding elements. By the choice of the polarity of this voltage a compressor or an expander may be obtained as desired.

In the regulating amplifier a valve is usually used whose slope varies with the grid voltage. In order to avoid non-linear distortions the input alternating voltage which such a valve receives must be amplified with a practically constant slope. The variations of this voltage must therefore be much smaller than the variations in the grid bias used for regulation. In general therefore the regulating amplifier will only be able to handle signals which are too small to give proper detection. It is therefore necessary to amplify the signal before it is detected, and to use for this either the amplifier proper or a separate detector amplifier. This brings us to the block diagrams of *figs. 5a* and *b*.

The difference between 5*a* and *b* is that the amplification factor in case *a* is determined by the input voltage and in case *b* by the output voltage of the regulating amplifier. The use of the latter circuit may, however, be accompanied by difficulties, because regulation by means of the output voltage may lead to instability. This may be explained as follows.

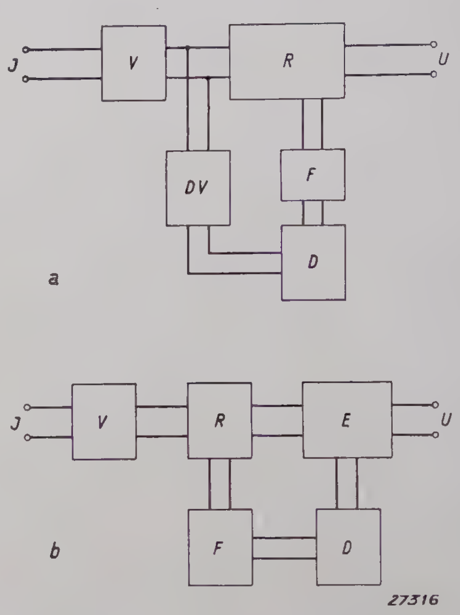

Fig. 5. Diagram of a compressor or an expander.
a) The amplification factor is determined by the input signal;
b) The amplification factor is determined by the output signal.
V pre-amplifier, *R* regulation stage, *F* filter, *D* detector, *DV* detector amplifier, *E* final amplifier.

If P_i is the level of the input signal (in nepers), P_u the level of the output signal, then:

$$P_u = P_i + \varphi ,$$

where φ is the amplification factor (also in nepers). Now the amplification factor of the regulating amplifier changes with the output signal. For small variations we may write:

$$\varphi = \varphi_0 + a\, P_u ,$$

where a is positive in the case of expansion and negative in that of compression. From the above equations it follows that:

$$P_u = P_i + \varphi_0 + a\, P_u ,$$

$$P_u = \frac{P_i + \varphi_0}{1 - a}$$

Stable functioning is only possible when the output voltage remains finite. a must therefore be negative or positive but less than one. In other words: stable working occurs only when the percentage increase of the amplification factor is less than the percentage increase of the output voltage [4]). If the amplification factor is determined by the input signal as in fig. 5*a*, such a phenomenon cannot occur. The output signal is then always finite, and is determined by an equation of the form:

$$P_u = (1 + a)\ P_i + \varphi_0.$$

Among the possible methods of construction of the regulator the following may be mentioned: change in amplification by change in the slope of a valve (this possibility was discussed above), and change in amplification by change in the external resistance of a valve. For this purpose a second valve may be used as loading resistance whose internal resistance depends closely on the grid voltage. The regulating voltage is supplied to the grid of this second valve.

Two regulating valves are often used in a push-pull circuit to combat secondary effects in regulation, such as non-linear phenomena and voltage surges.

B. Influence exerted on the amplification by changing the resistance of a filament

If use is made of a change in the resistance of a filament with the temperature, a material must be chosen for the filament with which a wide variation of resistance is possible. For this condition it is necessary not only that the material should have a large temperature coefficient of specific resistance, but also that it should be able to withstand a high temperature without changing its shape or melting. It is found that the maximum changes in resistance may be obtained with tungsten, although its temperature coefficient is smaller than that of iron; tungsten, however, can easily withstand temperatures of 2 100° C, while iron melts at 1 528° C. Moreover, tungsten is very suitable for the making of the filament which when sealed into a bulb in the form of a lamp forms an object which can easily be handled. Before going into the properties which the lamp should possess we shall first discuss several examples of circuits for expansion. Compression circuits may also be developed on the same principles; they may often be derived from the expansion circuit in a simple manner.

The latter possibility is offered by the bridge circuit as in *fig. 6*. The bridge consists of two lamps in two opposite branches and of two constant resistances R_1 and R_2. If the resistances are so adjusted that for room temperature of the filaments L_1 and L_2 the bridge is in equilibrium, the ratio between the output voltage and the input voltage is small for voltages which scarcely heat the filaments; for higher voltages, which do heat the filaments, the bridge is not in equilibrium and V_u/V_i will become greater.

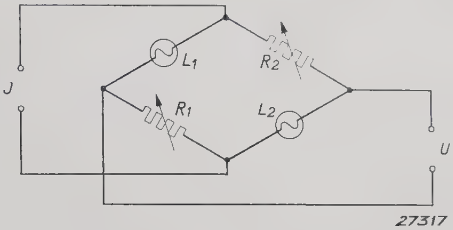

Fig. 6. Bridge circuit for obtaining the regulation voltage of an expander. The resistances R_1 and R_2 are so adjusted that the bridge is in equilibrium at room temperature of the filaments L_1 and L_2. When an alternating voltage is applied the temperature of the filaments increases. The bridge is then no longer in equilibrium and a voltage acts across the output terminals which increases more rapidly than the alternating voltage.

In this way an expander is obtained. By adjusting the bridge for equilibrium with hot filaments it is just possible to make V_u/V_i become greater for weaker signals; this results in a compressor.

Another possibility is the circuit of *fig.* 7. In this case use is made of an inverse feed-back which is dependent on the output voltage. The amplification factor μ of an inverse feed-back amplifier may be represented by [5]):

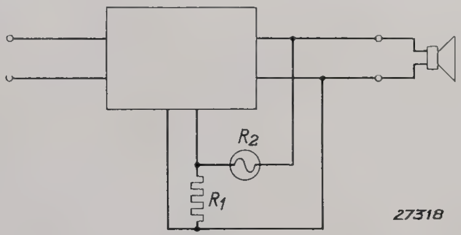

Fig. 7. A very simple expansion circuit, which uses a varying inverse feedback. With an increasing output-voltage the resistance R_2 of the lamp becomes greater. In this way the strength of inverse feedback is reduced and the amplification factor increases.

$$\mu = \frac{a}{1 + a\beta}\,.$$

a is here the amplification, *i.e.* the ratio of input to output voltage without inverse feed-back, and β is the ratio of the inverse feed-back voltage to the output voltage. In the case of fig. 7, therefore, $\beta = R_1 + (R_1 + R_2)$. By increasing resistance R_2,

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[4]) The condition is necessary but not sufficient by itself. Instability may for example also occur when a circuit as in fig. 5*b* is used for compression and a is negative. This possibility occurs, when due to incorrectly chosen filters, signal frequencies return to the regulator over the detector, thus forming a closed system which can continue to work by itself with sufficient amplification.

[5]) See the article "Inverse Feed-back" in Philips techn. Rev. **2**, 289, 1937.

β becomes smaller and therefore the amplification μ becomes greater.

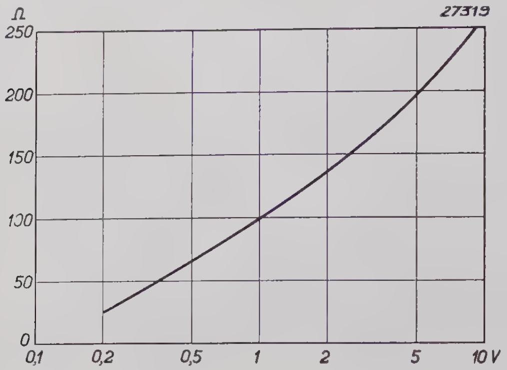

Fig. 8. Resistance of the lamp used for expansion circuits as a function of the voltage.

This circuit has the advantage of great simplicity; in order to obtain the desired form of expansion characteristic, however, several special features are required of the lamp:

1) In the region of the normal voltages which occur at the output end of a radio receiver the resistance of the lamp must change considerably.
2) The lamp should not take up too much energy since it does so at the expense of the energy delivered by the loudspeaker.
3) The times for heating and cooling of the filament must be such that the correct regulation times are obtained. This condition applies of course to every expansion circuit which uses heated filaments.

These requirements could only be satisfied by using a very thin wire wound in the shape of a spiral; one of the purposes of the spiral form is to increase the temperature of the wire with as little energy as possible. The filament is situated in a vacuum so that it can give off heat only by radiation. In order to give the resistance of the lamp a suitable value and to provide that it consumes only a small amount of energy it has been found necessary to use a wire of only 9 μ diameter.

The time necessary for heating and cooling of the lamp were found to correspond very well with the desired values; the time for heating up amounts to about 0.1 s and that for cooling off to about 0.6 s.

Fig. 8 gives the relation between the resistance of the lamp and the voltage, while *fig. 9* gives an example of an easily obtainable expansion characteristic.

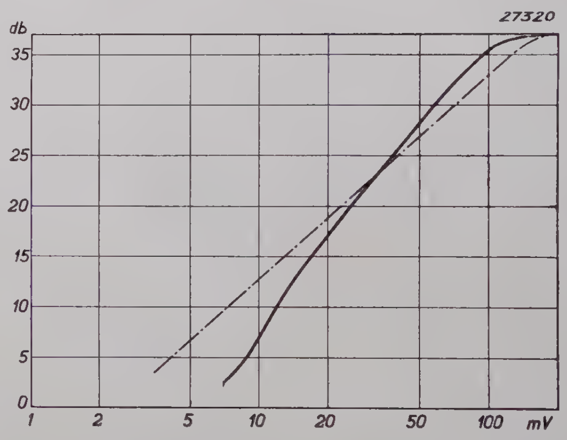

Fig. 9. Expansion characteristic obtained with a circuit as in fig. 7. An intensity range of 24 db at the input side is expanded to 34 db. The chain dotted line gives the characteristic in the absence of expansion.

PHENOMENA IN AMPLIFIER VALVES CAUSED BY SECONDARY EMISSION

by J. L. H. JONKER.

537.533.8 : 621.396.645.3

In amplifier valves secondary emission may occur not only from electrodes but also from non-conductors which are at a positive potential. In this article several phenomena are described which are connected with this secondary emission.
The secondary emission of the anode has an unfavourable effect on the characteristic of tetrodes. Improvement may be obtained by covering the anode with a suitable material or providing it with ribs, and further by employing an extra electrode and by utilizing the space charge in a suitable manner.
The secondary emission of insulators results from the fact that an insulator which is struck by electrons and emits secondary electrons may take on a considerable positive potential. This effect is applied in the fluorescent screen of cathode ray tubes, and may also occur as an undesired phenomenon in radio valves where it causes strong distortion and output damping. Finally several ways are indicated of combatting the secondary emission of insulators.

When a plate is struck by electrons which have been accelerated by a sufficiently high voltage, secondary electrons are freed from the plate as has been described in previous articles in this periodical [1, 2]).

In the second article cited it was explained how deliberate use can be made of the phenomenon of secondary emission to amplify electron currents; in this case specially prepared electrodes are used which give a high secondary emission upon bombardment with primary electrons. Secondary electrons may, however, appear in every amplifier valve when electrons which are accelerated by the voltages common in amplifier valves strike a conducting or insulating surface. In general the number of these secondary electrons, even in the case of surfaces which are not specially prepared, may be of the same order of magnitude as that of the primary electrons.

In this article we shall discuss the phenomena which occur in an amplifier valve as a result of this secondary emission, and we shall also study the available means of combatting secondary emission in cases where it is undesired, or at least of preventing its having an unfavourable effect on the action of the valve.

Secondary emission of conductors

As an example of a conductor on which an undesired secondary emission may occur we shall consider the anode of a tetrode, *i.e.* of a valve with a cathode, a control grid, a screen grid and an anode.

With such a valve, upon large changes of the anode voltage such as occur in final amplifier valves, the minima of the anode voltage may be considerably lower than the screen grid voltage. The continuous line in *fig. 1* represents the anode current which would flow if no secondary emission occurred, as a function of the anode voltage (at constant screen grid voltage). If, however, secondary emission does occur the current varies according to the dotted line.

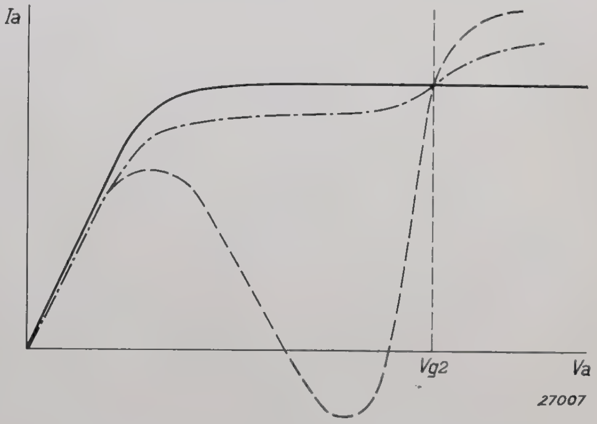

Fig. 1. Current-voltage curves of tetrodes.
--------- anode current of a tetrode as a function of the anode voltage. V_{g_2} is the screen grid voltage.
—·—·— current-voltage curve when secondary emission is partially suppressed by means of a layer of carbon and ribs on the anode.
———— current-voltage curve in the absence of secondary emission.

The difference between the two curves may be explained as follows. If the anode voltage is higher than the screen grid voltage, the secondary electrons which are freed from the anode are driven back to the anode by an opposing field. The primary electrons, much fewer in number, which strike the screen grid will also free secondary electrons. These electrons are drawn to the anode by the same field, so that the anode current is slightly higher

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[1]) H. Bruining, Secondary Electron Emission, Philips techn. Rev. 3, 80, 1938.

[2]) J. L. H. Jonker and M. C. Teves, Technical Applications of Secondary Emission, Philips techn. Rev. 3, 137, 1938.

with secondary emission than without it.

If the anode voltage becomes lower than the screen grid voltage, the direction of the field changes, and the secondary electrons from the anode will be attracted to the screen grid. The anode current therefore decreases suddenly and the screen grid current increases, which results in high distortions in the anode alternating current. The means available for combatting these undesired phenomena may be divided into two groups:

1) attempts may be made to keep the secondary emission of the anode low,
2) attempts may be made to make the action of the secondary electrons harmless by suitable construction of the anode or by the use of an extra electrode.

The possibilities of lowering the secondary emission have already been described in detail in this periodical (Bruining, *loc. cit.*).

The lowest secondary emission is obtained from a layer of carbon which is deposited in such a way that the surface is rough or flaky, so that the secondary electrons are for the most part captured in the cavities between the grains of carbon and cannot be drawn away. The secondary emission which has been lowered in this way, however, still amounts to 30 - 50% of the primary electron current. A complete suppression of secondary emission cannot therefore be achieved by this method, and in discharge tubes there are a number of factors acting which make it difficult to retain even these low values when the tube is in use. One of these factors has already been mentioned in a previous article, namely the alteration of the surface by the deposition of evaporated material, barium and barium oxide, from the hot cathode. The high temperature during the outgassing of the electrodes, the gases freed during the process of manufacture and the getter employed may also be factors causing a surface modification which increases the values of the secondary emission.

Considering the fact that suppression of secondary electron emission was found to be impossible, other methods were sought of neutralizing the effect of secondary emission. It is possible to do this to a great extent by giving the anode ribs or partitions (see *fig. 2*). The same effect is obtained in this way as by the use of a porous carbon layer. The secondary electrons freed between the partitions are to a large extent recaptured by the partitions and thus return to the anode.

In fig. 1 the line drawn thus: —·—·— represents the anode current of such a valve, which has in addition its anode and screen grid covered with a layer of carbon. As was to be expected the secondary electron current from the anode to the screen grid is considerably reduced but not completely suppressed. The remaining irregularity of the curve proves that the secondary emission is still appreciable.

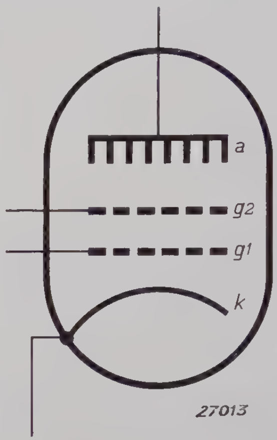


Fig. 2. Tetrode with ribbed anode. The secondary electrons which leave the anode are to a large extent recaptured by the ribs.

A completely effective method of preventing the passage of secondary electrons from the anode to the screen grid is the introduction of an extra electrode, a so-called suppressor grid, which when added to a tetrode converts it into a pentode. This method is used in most radio valves.

How does a suppressor grid work? Its action is based on the fact that the secondary electrons have for the greater part relatively low velocities, so that a counter voltage of 20 - 30 volts is sufficient to send practically all the secondary electrons back to the anode.

If a fine-meshed grid were placed in front of the anode and if it were kept continually about 20 volts lower in potential than the anode, secondary emission would be suppressed. Practically the same effect can be achieved by placing between screen

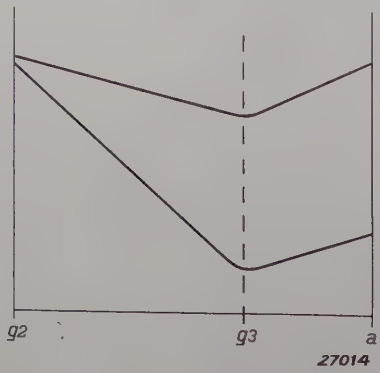


Fig. 3. Variation of the potential between screen grid and anode in a pentode without space charge (plane parallel electrodes).

grid and anode a wide-meshed grid which is connected to a point of low potential, for instance the cathode. By a suitable choice of the dimensions of the mesh and position of this grid the lowest voltage along the path of the electrons between anode and screen grid can always be kept sufficiently lower than the anode voltage to cause secondary electrons to return to the anode. On the other hand this potential must always be positive even with the lowest instantaneous anode voltage, since otherwise all electrons will not reach the anode. In *fig. 3* the variation of potential is given for two values of the anode voltage, space charges between screen grid and anode being neglected.

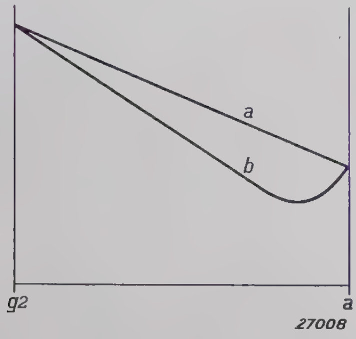


Fig. 4. Variation of potential between screen grid and anode in a tetrode; *a* without, and *b* with space charge. The space charge prevents the passage of secondary electrons from anode to screen grid.

The presence of the space charge has the result that the line representing the variation in potential between two flat electrodes is no longer straight, but curves. *Fig. 4b* shows the variation of potential between the screen grid and the anode as it would be with a large anode current (large space charge) a low anode voltage, and no suppressor grid.

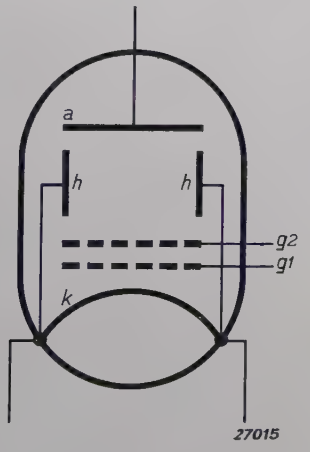


Fig. 5. In order to prevent the transition of secondary electrons from anode to screen grid, the potential in the space between these electrodes must be lowered. This is achieved here by means of the auxiliary electrodes *h* which are kept at cathode potential. At the same time the transition time of the electrons and therefore also the space charge is increased, whereby the potential is still further lowered.

It may be seen that with a large current between screen grid and anode a potential minimum may occur here also, and may be able of preventing the passage of secondary electrons between anode and screen grid.

A practical type of construction which makes use of this effect was obtained by combining the action of the space charge with that of an extra electrode, consisting here of two plates connected with the cathode (*fig.* 5). This construction is simpler than that with a suppressor grid and it entirely suppresses the transition of secondary electrons down to an anode voltage of about 30 V, as may be seen from *fig. 6* in which the variation of the anode current is given as a function of the anode voltage. The anode current remains fairly constant upon decrease of the anode voltage to about 30 V, and then decreases suddenly with a sharp bend.

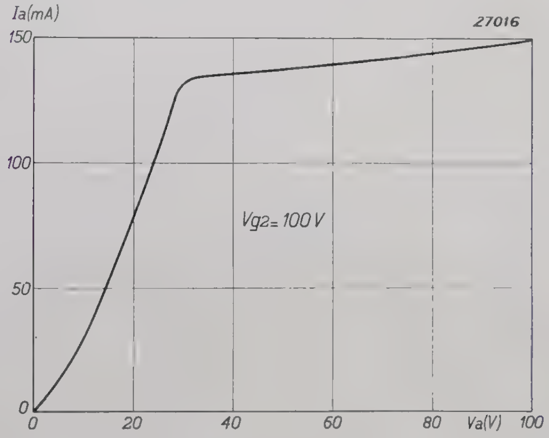


Fig. 6. I_a-V_a characteristic of a tetrode with auxiliary electrode as in fig. 5.

Secondary emission of insulators

Let us consider an insulating part of a radio valve which is struck by electrons, for instance an insulating support. This component, which may easily have a large secondary emission factor, will be connected to the different electrodes over the poorly conducting insulation. A given surface element of the insulating support may now be considered as a secondary emitting plate P (see *fig.* 7), which is connected over a high resistance R with a type of average voltage V_0 of the electrodes, which will for instance be somewhat lower than the anode voltage. This scheme corresponds exactly with that of a dynatron (see article quoted in footnote [2]), and the same is true of the current I_p of the secondary emitting plate as a function of its voltage. The characteristic is given in *fig. 8a*. With increasing voltage I_p at first increases, reaches a maximum and then decreases (it may even become negative), because the coefficient of secondary emission increases so much in a given range of voltages that the number of secondary electrons increases more rapidly than the number of primary electrons. As soon as the plate voltage is higher than the anode voltage V_a, however, the secondary electrons can no longer leave the plate and the current suddenly increases rapidly to the value which it would have in the absence of secondary emission.

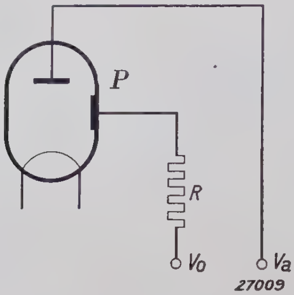


Fig. 7. Equivalent circuit for an insulating part of a radio valve which is struck by electrons.

What potential will the secondary emitting plate assume in a stationary state? From fig. 7 the following relation may be seen to hold between the current I_p and the voltage V_p on the plate:

$$V_p = V_0 - I_p R\,.$$

This relation is represented in fig. 8 (straight line b), together with the characteristic a which also gives a relation between I_p and V_p. The stationary states are given by the points of intersection p, q and r. The intersection q always occurs: the intersection p and r will not occur if the secondary emission is so low that the characteristic has for example the form of the dotted line curve. We see that the secondary emitting plate can adjust itself to different potentials when the secondary emission is high. The lowest potential (q) corresponds approximately to that of the cathode, the highest (p) to that of the anode; the adjustment r is not stable.

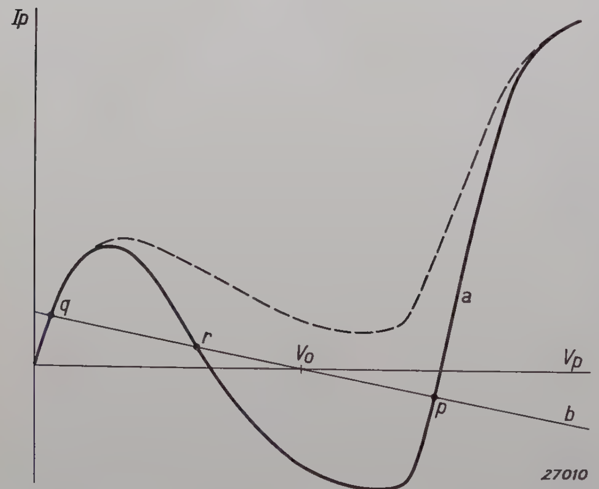


Fig. 8. Curve a: current I_p of a plate with a high secondary emission which is bombarded with electrons as a function of the plate voltage. With a lower secondary emission the current will vary according to the dotted-line curve.

Curve b: voltage V_p of the same plate as a function of the current when the plate is connected with a source of direct voltage V_0 over a high resistance.

The points of intersection of the lines a and b determine the stationary states. The adjustment has two values, given by p and q. Point r is an unstable state. In state p the potential of the plate is higher than the voltage V_0.

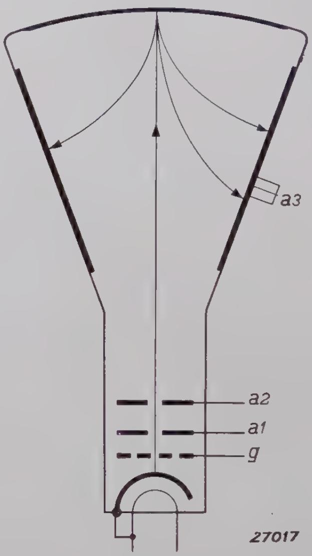


Fig. 9. Construction of a cathode ray tube. The collecting electrode a_3 has the function of providing that the fluorescent screen shall assume a positive potential upon being bombarded with electrons, and in addition of capturing the secondary electrons.

Let us assume for example that the state of the plate was originally given by the working point r, and that the voltage V_p has increased slightly due to a fluctuation in the secondary emission. The result is that the supply of electrons to the plate ($I_{\text{primary}} - I_{\text{secondary}}$) decreases more rapidly (curve a) than the loss of electrons over the leakage resistance R (curve b). The plate will therefore assume a positive charge, and as a result its potential will increase further until the stationary state p is reached.

The fact that an insulator can reach a high potential and give a high secondary emission upon being bombarded by electrons, sometimes leads to undesired phenomena in radio valves. Before going into this matter we shall show how this same phenomenon may be put to practical use in cathode ray tubes.

The fluorescent screen of cathode ray tubes consists of an insulating material and must be at a high potential in order that the electrons may strike it with sufficient kinetic energy to produce fluorescence. If the secondary emission of the screen were lower than the primary electron current, the screen would assume a negative charge and the high potential could not continue to exist. The screen must therefore have a high secondary emission. Furthermore, care must be taken to ensure that, upon switching on, the screen can reach a potential higher than r in fig. 8, otherwise it would not adjust itself to the working point p but to point q.

In *fig. 9* it is shown how the construction may be carried out practically. Close to the screen the inner wall of the tube is covered by an electrode which is raised to a high potential. This electrode has a two-fold purpose: first that of providing that the potential of the screen shall be such that upon switching on a sufficiently high secondary emission will occur, and second that of being able to draw the secondary electrons away rapidly.

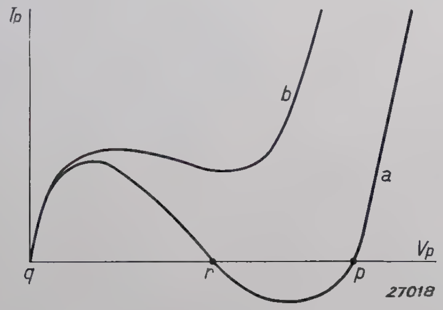


Fig. 10. Current from an insulating component in a radio valve as a function of the potential of that part; a at a high anode voltage, b at a low anode voltage.

As was stated above, the secondary emission of non-conductors may also occur as an undesired effect on the insulators and glass walls of radio valves. The phenomena may lead in two ways to disturbances: with power amplifier valves distortion occurs, with high-frequency amplifier valves an extra damping occurs in the output circuit.

With power amplifier valves where the alternating anode voltage has a large amplitude, the I_p - V_p characteristic of an insulator in the neighbourhood of the anode will vary very much. In certain cases the characteristic at the highest anode voltages may be such that a working point p of high potential exists, while this is not the case at the lowest anode voltage, because the secondary electrons from the insulator are not drawn away sufficiently rapidly (v. *fig. 10*). In such a case it may happen that the potential of the insulator upon rise and fall of the anode voltage jumps up and down between a high and a low value. Upon each jump in potential a charge may be induced on the modulating grid which causes transients in the anode current v. (*fig. 11*).

In high-frequency valves, where it is desirable that the anode current shall change little with the anode voltage (*i.e.* that the internal resistance shall be high), difficulties may be experienced due to secondary electrons which are emitted from an insulator and reach the anode. Considering the fact that the insulator itself can conduct no current, this extra current is equal to the primary electron current to the insulator. This primary current is in

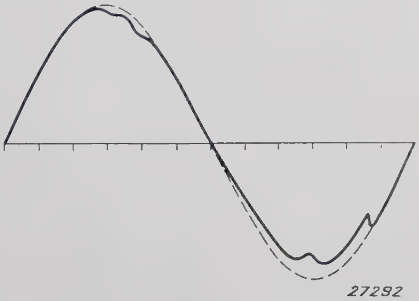
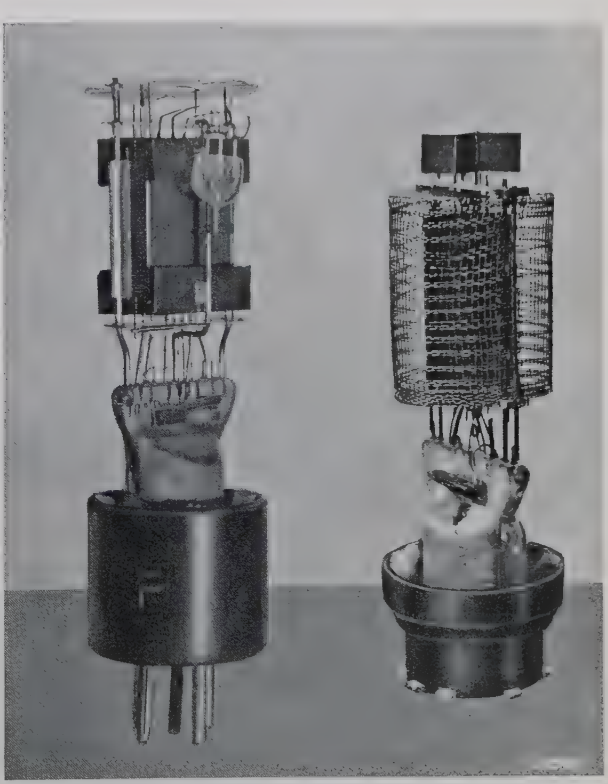


Fig. 11. Variation of the anode current for a power amplifier valve with sinusoidal grid voltage. The curve exhibits a number of irregularities due to a sudden jump in the potential of an insulating support or of the glass wall.



a *b*

Fig. 12 *a*) Power amplifier valve in which the mica supporting plates and the glass wall are shielded against bombardment with electrons by enclosing caps at the ends of the system. *b*) In an amplifier valve with a gauze anode the glass wall is exposed to a strong bombardment by electrons. In order to avoid this the anode is surrounded by a gauze cage which is connected to the cathode.

general very greatly influenced by the potential of the insulator which will change about equally with the anode voltage. The secondary electron current which reaches the anode will therefore also change sharply with the anode voltage, and this means that the internal resistance becomes considerably lower and the amplification of the high-frequency stage diminishes.

In order to avoid these harmful effects here again several methods may be chosen. When, for example, the disturbing phenomenum is due to insulating supports within the system, the most practical solution will be to cover them with a substance whose secondary emission is less than unity (for instance a layer of carbon). If the danger spot is the inner side of the bulb, the jump in potential can also be avoided by earthing this surface through a capacity. In order to do this the outside of the bulb may be covered with a layer of metal which is kept at a low potential (that of the cathode for instance). Finally the charging of the wall of the bulb may be avoided by entirely preventing electrons from leaving the electrode system and reaching the glass wall. This may be achieved by means of shields. *Fig. 12a* shows a power amplifier valve with a massive anode whose ends are closed by caps which make it impossible for electrons to leave the anode. If an anode in the form of a gauze is used as is often necessary in order to improve the heat radiation of the components within the anode, this shielding must also be extended behind the anode. For this purpose a wire gauze cage at cathode potential is suitable. Electrons are unable to pass through this cage to the outside (fig. 12*b*). Shields with a low potential may also be introduced in front of the much used mica supports at the extremities of the system in order to prevent their being struck by electrons.

AN APPARATUS FOR THE MEASUREMENT OF SCANNING SPEEDS OF CATHODE RAY TUBES

by L. BLOK.

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A simple apparatus is described for the determination of the greatest scanning speed of cathode ray tubes which can be photographed. The light spot on the screen is allowed to describe a logarithmic spiral, at every point of which the speed can easily be determined. The point of least intensity on the spiral which is still sufficiently visible in the photograph determines the maximum scanning speed required.

If, with the help of a cathode ray tube, phenomena are investigated which are not periodic or stationary, but only occur once, it will in general be found practical to record the phenomenon photographically. In the most commonly occurring cases the details cannot be adequately studied by visual observation.

As examples of phenomena which are investigated in this way we may mention the switching on of transformers, break-down in the testing of insulating materials, back-surge in rectifiers, atmospheric discharges, etc.

In the photographic recording of such a phenomenon the blackening of the light-sensitive plate will depend on:

a) the brightness B of the cathode ray light spot,
b) the diameter of the spot D,
c) the velocity v at which the spot moves,
d) the optical enlargement N,
e) the light sensitivity η of the photographic material.

A detailed treatment of the relation between blackening and the factors a) to e) has already been published in this periodical [1]), together with a discussion of measurements relating to the maximum scanning speed. As a control in the manufacture of cathode ray tubes it is desirable to be able to determine this scanning speed in a simple way. In the following a description is given of a measuring apparatus solved for this purpose.

Principle

In order to determine the scanning speed by means of a single photograph it is necessary to allow the spot to describe a path on which the velocity changes continuously, while at every point of the path the velocity must be known with sufficient accuracy. One may then determine on the photograph the point where the path of the spot is still just sufficiently visible. The velocity at that point is then the maximum scanning speed which can be photographed under the given conditions.

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[1]) J. F. H. Custers, The recording of rapidly occurring phenomena with the aid of the cathode ray tube and the camera, Philips techn. Rev. 2, 148, 1937.

A very simple solution of the problem is obtained when the light spot describes a logarithmic spiral with a constant angular velocity.

This curve may be represented in polar coordinates by the following equation:

$$\varrho = A\ e^{-a\varphi} \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (1)$$

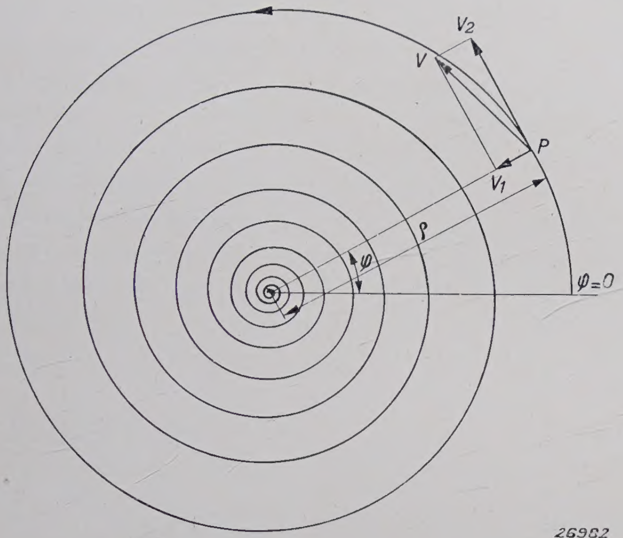

Fig. 1. Logarithmic spiral: $\varrho = A\ e^{-a\varphi}$

The exponent of *e* is taken negative so that with increasing argument φ the radius vector ϱ decreases (*fig. 1*). If φ is made linearly dependent on the time by setting

$$\varphi = \omega t \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (2)$$

where ω is a suitable angular velocity we obtain:

$$\varrho = A\ e^{-a\omega t} \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (3)$$

when $t = 0$, $\varrho = A$, when $t = \infty$, $\varrho = 0$.

The velocity at any point *P* of the spiral (*v.* fig. 1) is given by:

$$v = \sqrt{v_1^2 + v_2^2},$$

where v_1 is the radial velocity and v_2 the velocity perpendicular to the radius vector. We now have the relation:

$$v_1 = \frac{d\varrho}{dt} \text{ and}$$

$$v_2 = \varrho \frac{d\varphi}{dt} = \varrho\ \omega\ .$$

From equation (3) we find that:

$$v_1 = \frac{d\varrho}{dt} = -a\ \omega\ A\ e^{-a\omega t} = -a\ \omega\ \varrho\ ,$$

so that:

$$v = \sqrt{a^2\omega^2\varrho^2 + \varrho^2\omega^2} = \varrho\ \omega \sqrt{a^2 + 1} \quad \cdot \cdot \cdot \quad (4)$$

If a^2 is made small with respect to unity, the radial velocity v_1 becomes small with respect to the velocity v_2, and the distance between successive coils of the spiral becomes small with respect to the radius ϱ. Then for the velocity v we obtain by approximation:

$$v = \varrho\ \omega \quad \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \quad (5)$$

This expression gives the velocity of a point which describes a circle with an angular velocity ω and a radius ϱ. The approximation employed therefore comes down to this, that the number of windings of the spiral must be so great that an element of the curve may be considered as an element of a circle.

Application of principle

In order to find out how a spiral can be obtained on a cathode ray tube by an electrical method, we pass over to rectangular coordinates.

For this purpose we take:

$$x = \varrho \cos \varphi = Ae^{-a\varphi} \cos \varphi\ ,$$
$$y = \varrho \sin \varphi = Ae^{-a\varphi} \sin \varphi\ .$$

With $\varphi = Qt$ this becomes:

$$x = A\ e^{-bt} \cos \omega t = A\ e^{-bt} \sin \left(\omega t + \frac{\pi}{2}\right),$$
$$y = A\ e^{-bt} \sin \omega t\ ,$$

where $a\omega$ is set equal to b.

x and y as functions of the time t have the form of two damped oscillations which differ in phase by 90°. Since the deflection of the spot on the screen is proportional to the potential difference between the plates, it is sufficient to apply a damped sinusoidal oscillation to each set of plates differing in phase by 90°.

Such a voltage is obtained in a simple manner by giving an *LCR* circuit an electrical impulse, and allowing it to die out in oscillations of its own frequency according to the well-known equation:

$$V_t = V_0\, e^{-\frac{R}{2L}t} \cos \omega t,$$

where V_0 is the voltage on the circuit due to the impulse at the moment $t = 0$, V_t the voltage at the time t, R the series resistance, L the self-inductance of the circuit, $R/2L$ the damping factor and $\omega = 2\pi f$, in which f is the frequency of the circuit itself.

By applying this voltage to the primary winding *P* of a transformer which has two separate equal secondary windings S_1 and S_2 (*fig. 2*), two similar secondary voltages are obtained of the same form as the primary voltage.

In order to obtain the desired phase difference, S_1 is loaded with the resistance R_1 and the condensers C_1 and C_2, and S_2 with R_2, R_3 and C_3, which are chosen so large that:

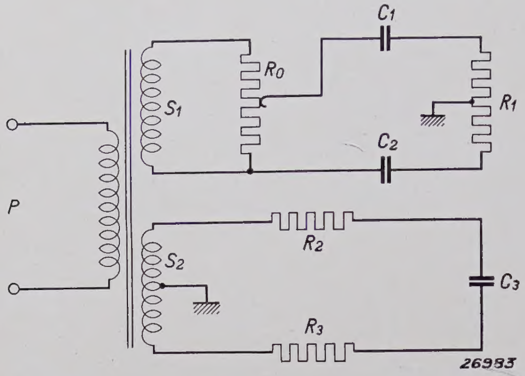

Fig. 2. Transformer with two similar symmetrically loaded secondary windings. The voltages on R_1 and C_3 differ 90° in phase and are symmetrical with respect to earth.

$$\frac{1}{\omega C_1}+\frac{1}{\omega C_2}=R_1 \quad \text{en} \quad R_2+R_3=\frac{1}{\omega C_3},$$

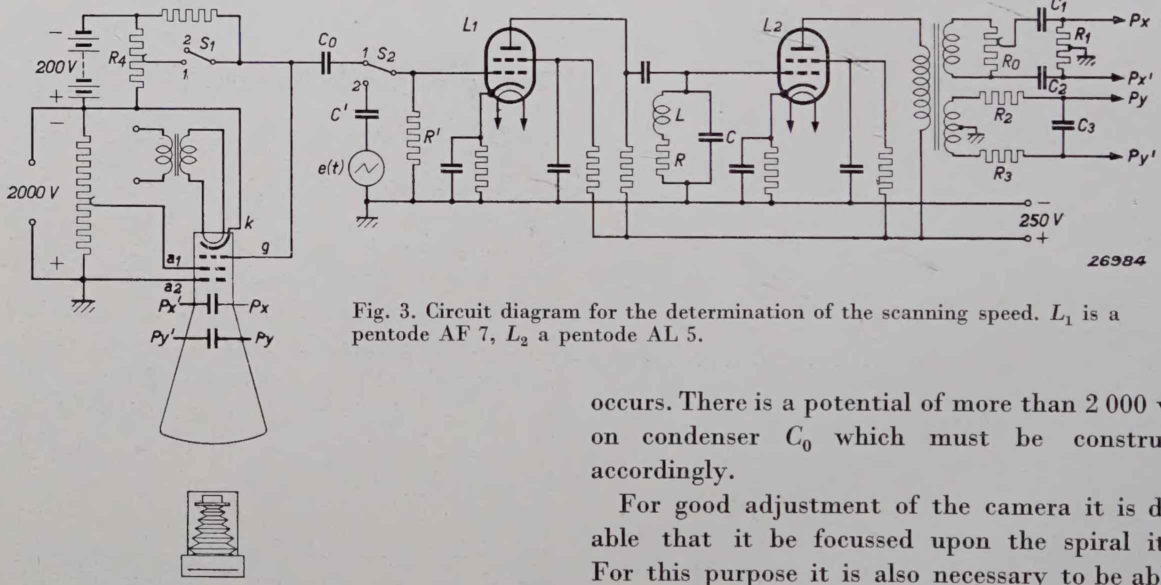

Fig. 3. Circuit diagram for the determination of the scanning speed. L_1 is a pentode AF 7, L_2 a pentode AL 5.

while in addition it is provided that:

$$R_1 = 2\,R_2 = 2\,R_3 \text{ and}$$
$$C_1 = C_2 = 2\,C_3\,.$$

In this way the voltage V_{R1} on R_1 is made equal to the voltage V_{C3} on C_3, while both are symmetrical with respect to earth and, moreover, the phase difference between V_{R1} and V_{C3} is exactly 90°.

With a cathode ray tube the proportionality factor between voltage and deflection is not the same for both pairs of deflection plates. The spiral obtained will therefore be "oval". By applying the voltage V_{R1} which can be regulated with the potentiometer R_0 to the more sensitive plates, this difference may be compensated and the spiral becomes "circular".

Description of the circuit

The diagram of the circuit may be seen in *fig. 3*. The positive pole of the high voltage apparatus which supplies the anode voltage is earthed. When the switch S_1 is in position *1*, with the help of potentiometer R_4 the voltage of the grid *g* of the cathode ray tube can be regulated, and thereby the strength of the electron current. When S_1 is in position *2*, *g* becomes about 200 volts more negative than the cathode *k* and the current of electrons is thereby suppressed.

With switch S_2 in position *1*, on changing S_1 from *2* to *1*, the adjusted electron current begins to flow and a voltage impulse occurs on the grid of valve L_1. The oscillating circuit *LRC* thereby receives an impulse so that on the primary winding of the transformer in the anode circuit of L_2 the desired damped sinusoidal oscillation occurs. There is a potential of more than 2 000 volts on condenser C_0 which must be constructed accordingly.

For good adjustment of the camera it is desirable that it be focussed upon the spiral itself. For this purpose it is also necessary to be able to obtain a permanent image of the spiral on the screen of the cathode ray tube. To do this, a sawtooth voltage generator *e*(*t*) is connected over the condenser *C'* by means of switch S_2 in position *2*. When *R'* and *C'* are correctly chosen, this sawtooth voltage *e*(*t*) gives periodic impulses to L_1 with a frequency depending on the frequency of the sawtooth voltage. For the circuit in which this voltage works the following holds:

$$e(t) = V_{C'} + V_{R'}\,,$$

in which $V_{C'}$ is the voltage on the condenser *C'* and $V_{R'}$ that on *R'*.

Upon substituting $V_{C'} = \int \frac{i}{C'}\,dt$ where *i* is the prevailing current and $i = V_{R'}/R'$, we may write:

$$e(t) = \int \frac{V_{R'}}{R'C'}\,\mathrm{d}t + V_{R'}, \quad \text{or, differentiating,}$$

$$\frac{\mathrm{d}\ e(t)}{\mathrm{d}t} = \frac{V_{R'}}{R'C'} + \frac{\mathrm{d}}{\mathrm{d}t}\,V_{R'}.$$

If $C'R'$ is sufficiently small, the first term of the right hand member of the equation dominates, and we may safely write the voltage derivation in approximation:

$$\frac{\mathrm{d}\,e(t)}{\mathrm{d}t} = \frac{V_{R'}}{R'C'}$$

The voltage on R' and therefore supplied to the grid of L_1 is proportional to the derivative of the voltage $e(t)$ with respect to time.

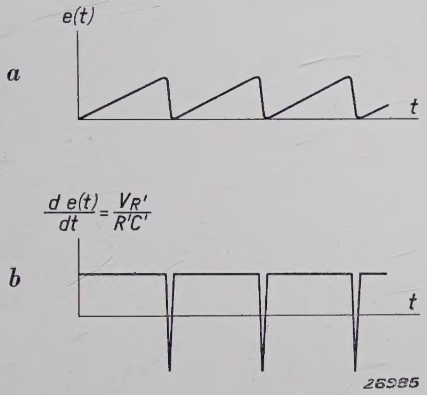

Fig. 4. Form of the sawtooth voltage $e(t)$ and of its derivation de/dt as a function of the time.

The form of the voltage $e(t)$ as a function of the time is indicated in *fig. 4a*, while in fig. 4*b* the variation of $V_{R'}$ as a function of t is drawn for sufficiently small values of $C'R'$. The latter figure shows plainly the occurrence of periodic impulses. Each of these impulses causes the spiral to be described once. In this way a permanent image appears on the screen of the tube. If the time between two impulses is made shorter than that necessary for the almost complete fading of the oscillations of the circuit, the light spot can no longer reach its point of rest. It then does not form a point in the center, but ends at an arbitrary point on one of the windings. An interesting effect is obtained when the frequency of the impulses is continously increased. The spiral is then seen to be erased from the centre outwards.

In recording a spiral the method is as follows. S_1 is set in position *1*, S_2 in position *2* and the camera is focussed on the spiral on the screen. After the lens has been closed the plate or film is introduced. S_1 is then set on *2* and S_2 on *1*, the shutter is opened and S_1 switched back to *1*, which causes the spiral to be described once on the screen. Then S_1 is returned to position *2*. *Fig. 5* shows a photograph taken in the way described with a Philips cathode ray tube DG 16 with a green-fluorescing screen. The scanning velocity reached amounts to (formula (5)): $v = \varrho \cdot 2\,\pi\,f = 3.5 \times 2\,\pi \times 1\,000 = 22\,000$ cm/s $=$ 220 m/s. If the photograph is taken smaller than the true size of the image on the screen, for instance six times reduced, then, *ceteris paribus*, the maximum scanning speed which may be photographed is about three times as great as in a photograph in natural size.

In measurements carried out on this principle the maximum scanning speed can be determined as a function of the anode voltage and the electron current with all types of tubes. Moreover, this method presents a means on the one hand of choosing the most sensitive photographic material in connection with a given fluorescent substance on the screen of the cathode ray tube, and on the other hand of comparing the quality of different fluorescing substances.

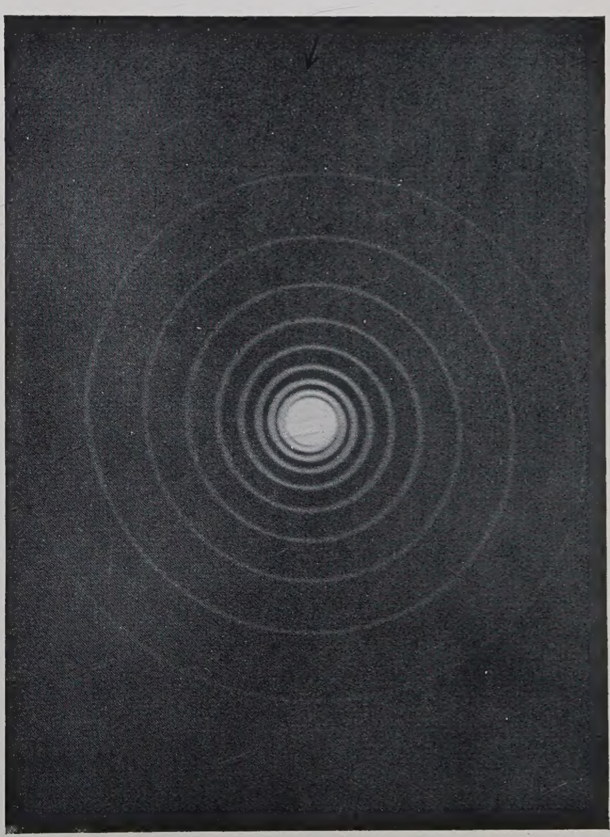

Fig. 5. Photograph for the determination of the scanning speed of a cathode ray tube DG 16. Electron current 50 μA, anode voltage 2 000 volts, ratio of size of photograph to object 1 : 1, aperture of lens 1 : 6.3, Agfa Isochrom plate. $\omega = 2\,\pi f = 2\,\pi\,1\,000$. The spiral is still just visible for $\varrho = 3.5$ cm. Maximum scanning speed 220 m/s. The enlargement of the reproduction is 1 : 3.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS GLOEILAMPENFABRIEKEN

1286*: H. C. Hamaker: Potential curves as a basis for the discussion of colloidal phenomena (Chem. Weekbl. **35,** 47 - 57, Jan. 1938 [1]).

For the contents of this lecture the reader may be referred to the original publications **1154, 1174** and **1211.** In particular this article gives a more general formulation of the problem treated in **1174.**

1287*: E. J. W. Verwey: Double layer and stability of lyophobic colloids (Chem. Weekbl. **35,** 70 - 79, Jan. 1938 [1]).

On the basis of observations on silver iodine sol the stability of colloids is described as due to the electrical double layer present on these colloids.

1288: N. W. Timoféeff-Ressovsky, K. G. Zimmer and F. A. Heyn: Auslösung von Mutationen an Drosophila melanogaster durch schnelle Li + D-Neutronen (Naturwissenschaften **26,** 108 - 109, Feb. 1938).

A lithium plate bombarded by rapid deutons emits a large number of rapid neutrons. These are used to caused mutations in flies.

1289: W. G. Burgers and J. J. A. Ploos van Amstel: Electron-optical observation of transition of α- into β-zirconium (Nature **141,** 330, Feb. 1938).

Electron-microscopic observations or zirconium are found to give results in agreement with the conclusion drawn from X-ray photographs, that the transition between α and cubic β-zirconium takes place by a homogeneous slipping and stretching (or compression) of connected lattice regions.

1290: W. G. Burgers and J. J. A. Ploos van Amstel: Lecture-room demonstration of electron-optical crystal patterns (Nature **141,** 370, Feb. 1938).

A description is given of the way in which an electron microscope can be constructed which is so powerful that the picture of the crystal structure of the metal surface produced on the fluorescent screen can be projected optically on a screen 50 by 50 cm, upon which a picture is then obtained which is suitable for demonstration in a lecture room.

1291: M. J. O. Strutt: Die charakteristischen Admittanzen von Mischröhren für Frequenzen bis 70 Megahertz (El. Nachr. Techn. **15,** 10 -17, Jan. 1938).

The most important properties to be measured on frequency changing valves (octodes and hexodes) are discussed, followed by a treatment of a circuit and a measuring arrangement which can be used to about 1.5 megacycles/sec.

Input and output admittance and conversion slope are determined for octodes type AK 2 and hexodes type ACH 1, as well as the admittance between first and fourth grids of the octode. Special attention is given to the shielding of the measuring arrangement for short waves. Measuring results to 50 megacycles/sec. are given. Finally measurements and calculations on the induction effect in octodes are discussed.

1292: A. A. Kruithof and F. M. Penning: Contribution of the photoelectric effect to the sparking mechanism in the noble gases at high pressures (Physica **5,** 203 - 204, Mar. 1938).

The ratio of the number of excitations to the number of ionizations caused by electrons in a pure gas increases sharply when the quotient of the electrical field strength E divided by the pressure p decreases. At values of E/p which are considerably lower than that of the minimum breakdown voltage, an increase in the number of electrons freed from the cathode per positive ion was found for various rare gases. This increase becomes understandable if in the breakdown mechanism account is taken of the freeing of electrons from the cathode by radiation.

1293: J. L. H. Jonker and A. J. W. M. van Overbeek: The application of secondary emission in amplifying valves (Wirel. Eng. **15,** 150 - 156, Mar. 1938).

The use of secondary emission for amplification in radio valves is treated in detail. The same subject was discussed more briefly in the May number of this periodical (Philips techn. Rev. **3,** 137, 1938).

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*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Natuurkundig Laboratorium, N.V. Philips' Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.

[1] **1286*** and **1287*** are lectures given at a symposium on the dynamics of hydrophobe suspensions and emulsions which was held on Nov. 5th and 6th 1937 in Utrecht. All the lectures given in this symposium, as reprints from the Chem. Weekblad, have been collected into a booklet which is published by Centen in Amsterdam at a price of *f* 4.— ($ 2.25).